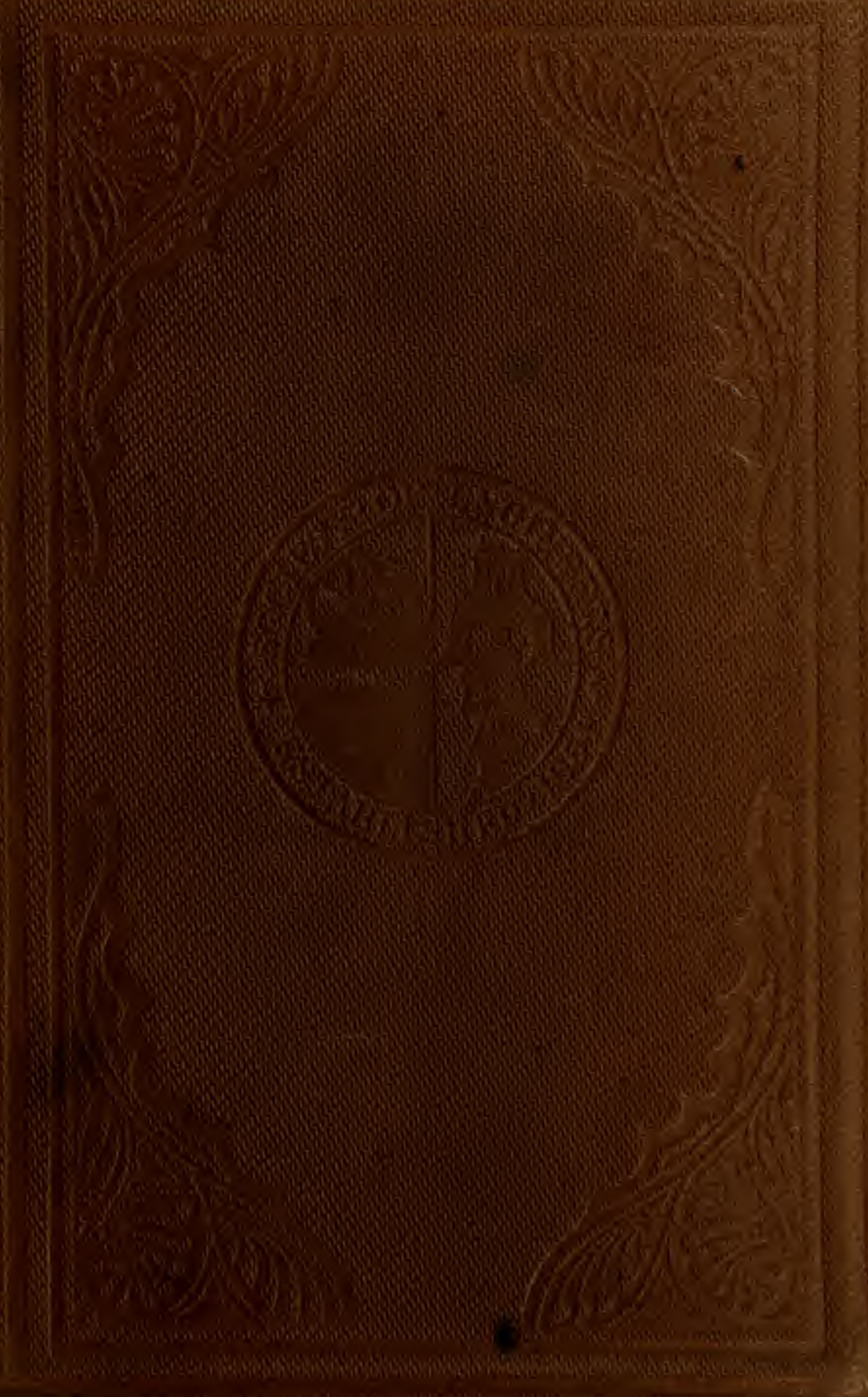

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SOCIETY OF ENGINEERS

ESTABLISHED MAY 1854

Journal and

TRANSACTIONS FOR 1895

AND

GENERAL INDEX, 1857 TO 1895

EDITED BY

G. A. PRYCE CUXSON

SECRETARY

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PAPERS AND PREMIUMS.

The Council of the Society of Engineers invites original communications from Members and Associates, as well as from others who do not belong to the Society, on subjects connected with any branch of Engineering.

For any papers that may be considered sufficiently meritorious the Council may at discretion award one or other of the following Premiums, viz.:—

1. The President's Premium, given by the President, and consisting of a Gold Medal of the annual value of Five Guineas.
2. The Bessemer Premium, given by Sir Henry Bessemer, F.R.S., Hon. Member, of the annual value of Five Guineas.
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4. The Society's Premiums, given by the Society, of an aggregate annual value not exceeding Twenty Pounds.

The number and value of the Society's Premiums are decided by the Council according to the number of meritorious papers read during the year.

By the Rules of the Society, Members of Council are debarred from receiving Premiums.

PREMIUMS FOR 1895.

At a Meeting of the Society, held on February 3, 1896, the following Premiums of Books, &c., were awarded, viz.:—

The President's Gold Medal to:

Reginald Empson Middleton, for his paper on The Relative Value of Percolation Gauges.

The Bessemer Premium to:

Thomas Andrews, F.R.S., for his paper on The Effect of Strain on Railway Axles, and the Minimum Flexion Resistance Point in Axles.

The Rawlinson Premium to:

David Butler Butler, for his paper on Portland Cement; some points in its Testing, Uses and Abuses.

The Society's Premium to:

William Thomas Sugg, for his paper on Ventilation and Warming.

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SOCIETY OF ENGINEERS.

ESTABLISHED MAY 1854.

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1896

TRANSACTIONS, &c.

February 4th, 1895.

INAUGURAL ADDRESS.

By WILLIAM G. PEIRCE, President.

My first and most agreeable duty on taking the chair of office is to express to you my sincere thanks for having elected me as President of our Society, thus placing me in the post of honour at its head. The honour has, however, owing to a most regrettable circumstance, fallen upon me before it was my due. In consequence of the lamented death of our late senior Vice-President, Mr. Henry Faija, I am unexpectedly called upon to assume the presidential duties out of the usual rotation. This circumstance, coupled with the pressure of professional work, obliges me to ask your indulgence for any shortcomings which may be found in this address.

My position in this respect is rendered all the more difficult, inasmuch as I succeed to a President, Mr. George A. Goodwin, whose inaugural address was an epitome of the most recent engineering practice in almost every department, and will form an invaluable standard of reference in our Transactions. Nor is it alone with regard to the able address of my predecessor that I have cause for misgivings. I cannot help feeling that he filled the office of President with such signal ability and success, and maintained so thoroughly the status of our Society, that I am almost disposed to distrust myself upon entering my year of work. But however perfectly he discharged his duties —and all will admit they were discharged most perfectly—I derive hope from the fact that my desire to succeed is no less earnest than his could have been, and I can only hope that my endeavours to accomplish all that can be done for the good of the Society will be as successful as his were.

I feel that the difficulty of presenting you with an address worthy of the Society is further increased by the circumstance that there are at present so few works of importance for me to deal with, and I am therefore at a loss to find new matter for review. Then, again, my difficulty is accentuated by the fact that our esteemed past President, Mr. William A. Valon, only two years ago, entered so fully into matters relating to water supply—to which branch of engineering I have devoted the greater part of my life — and gave us so much valuable information on the subject, that I fear I may tax your patience in some cases with repetitions, which, however, being unavoidable, I trust you will excuse.

Following the time-honoured example of my predecessors in this chair, I will first refer to the work of the Society during the past year. First, then, with reference to the papers that have been read and discussed at our monthly meetings, there can be no doubt that they include carefully selected subjects which bring out good discussion and attract large gatherings. Such papers are the mainstay and strength of the Society.

In March last a paper was read by Mr. Henry O'Connor on Pile-driving. The author first dealt with discrepancies observable between the formulæ put forward by various engineers for calculating the weight necessary for driving piles, showing that by the one 72 tons would suffice to sink the pile further, whilst another formula gave 300 tons as necessary for the same operation. This discrepancy was accounted for by the difference in various strata which the author said was not sufficiently allowed for. He therefore adopted a system of finding out the resistance of each layer of the ground, and also the force required to withdraw a pile. This paper was considered worthy of a premium, but Mr. O'Connor having since reading it been elected on the Council, is thereby disqualified from receiving one.

In April, Mr. E. Lloyd Pease read a paper on Gasholder Construction, in which he called attention to discrepancies in designs of holders. He suggested the possibility of a large economy in construction when dealing with the strength of a holder under the conditions of working and as a structure.

In May, a paper was read by Mr. R. Nelson Boyd on a Deep Boring near Freistadt, Austria, by the Canadian system. After explaining the different systems of boring adopted, he stated the work in question was undertaken for proving an unknown position of the Ostrau-Karwin Coal Fields. The diamond drill was first selected, but could not be applied, owing to the want of water, and he eventually adopted the Canadian rig. The boring reached a depth of 1010 feet. Inflammable gas was met with at 960 feet; the noise of the gas escaping up the borehole was like the boiling of a great caldron. The Canadian system has many advantages, for by the use of the jars greater rapidity of drilling is obtained, and it is possible to get an approximate section in soft ground which cannot be secured even by the diamond drill. The author was awarded the Rawlinson premium for this paper.

In June a paper was read by Mr. E. C. de Segundo on Power Distribution by Electricity, Water and Gas. The author dealt at some length with the meaning and application of the word "efficiency," passing on to the efficiency of the steam engine and boiler and to the calorific value of town gas. In this connection he referred to Mr. Dowson's claim to produce one brake horse-power hour by a gas engine with a consumption of one pound of anthracite in his generator. The author gave some practical examples of efficiency of electric generating plant, and compared it with the working of the London Hydraulic Power Company, also referring to the hydro-electric scheme of the late Van Rysselbergh and the importance of amalgamation of the electric light and gas interests for the benefit of the community at large. The Bessemer Premium was awarded to Mr. Segundo for this paper.

In October a paper was read on the Utilisation of Town Refuse for Generating Steam. The recognised means of disposal is now by fire, which, without doubt, destroys all germs of disease, and the author advocated that the heat set free by the process of destruction should be utilised by providing a special furnace or destructor, in which the heat usually allowed to go to waste is utilised for production of steam. The author claimed that the scheme was particularly applicable to the generation of electricity by the steam thus produced; also for use in pumping at baths and wash-houses. The discussion on this important paper was adjourned to the November meeting, so numerous were the speakers who had information to impart or criticisms to offer on the subject, thus testifying to the value of the paper itself. The Council marked their appreciation of Mr. Baker's paper by awarding the author the President's gold medal.

At the December meeting we had a very interesting paper from Mr. H. B. Ransom on the Principles and Practice of Hydro-extraction. After giving a brief outline of the laws which govern centrifugal force, the author pointed out the various applications for these machines, and explained why some materials could be successfully dealt with by them whilst others could not. It was made clear that the greatest dangers attending the use of centrifugal machines were driving them by badly governed engines and by improper feeding and attention. With regard to the design and construction of the basket, the author stated that the results of his investigations showed that the factor of safety of a plate basket was only 3, as compared with the factor of safety of a steel wire basket, which was nearly 13. Mr. Ransom also dealt with the construction of direct-driven centrifugals, and he gave some interesting figures in relation to the inertia of the reciprocating portions of these engines. It appears, for instance, that in a 12 by 8 inch engine making 1200 revolutions per minute, the force necessary to start the piston at the beginning of a stroke would amount to nearly 3½ tons. For this paper the author was awarded a Society's gold medal.

The professional visits made by the Society during the past vacation have been well attended and greatly appreciated, as the numbers testify, and as they always have been. The first visit was paid, in June, to the South Metropolitan Gas-works, Old Kent Road. These are the old works of the South Metropolitan Company founded in the year 1834 and incorporated in 1842. In 1880 the Surrey Consumers Gas Company was amalgamated with the South Metropolitan Gas Company, and in the same year the united companies absorbed the Phœnix Gas Light and Coke Company. Following this, in the year 1885, the Woolwich, Plumstead and Charlton Consumers Gas Company and the Woolwich Equitable Gas Company were also absorbed.

The position of the Old Kent Road Works is favourable for the distribution of gas and also for the sale of coke. The maximum manufacturing capacity is equal to 9,000,000 cubic feet of gas per day, equal to 900 tons of coal, producing 400 tons of coke for sale, 9000 gallons of tar, and 27,000 gallons of ammoniacal liquor. These figures represent about one-fourth of the total maximum daily production of the company. The company recently reduced the price of gas to 2*s.* 4*d.* per 1000 cubic feet, which is the lowest price at which gas is supplied in or near London. Gas is now supplied to the artisan class by means of an automatic prepayment meter, and meters of this type are now being fixed at the rate of 300 per week, the cost of fittings and hire of a cooking stove being included in price paid for the gas.

In July a visit was paid to the Royal Small Arms Factory at Enfield, and the inspection was much appreciated by the visitors, who had the opportunity of witnessing the manufacture of rifles, machine guns, swords and sword bayonets, and all their numerous components at every stage. It would be tedious to enumerate all these departments and operations, but I may refer in passing to the large machine room, where we were shown no fewer than 1503 machines in operation. The assembling department was also a centre of interest. The various departments are capable of turning out 2000 magazine rifles with accessories, also 1000 spare barrels and bayonets, in addition to swords and cutlasses, in a working week of forty-eight hours. I may add that the number of different operations in the manufacture of the Lee-Metford rifle proper is about 1500. With the accessories such as the sight protector, bayonet, &c., the number is increased to about 1750.

In October the Society visited the works of Messrs. Siemens Brothers & Co., at Charlton, who are the well-known manufacturers of electrical plant and machinery and submarine telegraph cables. At their works all the machinery in the shops is driven by electric motors. The construction of dynamos and alternators was seen to advantage in the new dynamo shops, where there is a very fine plant of machinery and motors. General erecting work is carried on in the old dynamo shop, while in the milling shop are a large number of milling and other machines. The manufacture of the carbons and of the rubber for insulating purposes were among the other matters of interest inspected. The central power and lighting station contains four engines, one being a Belliss compound vertical of 300 I.H.P., and the other three being Willans' compound transfer condensing, each of 300 I.H.P. Coupled direct to these engines are four Siemens' dynamos of their H.B. type for 120 volts, 2000 amperes. The electrical energy is distributed by means of underground lead-cased cables. There are in all fifty-four electric motors in the works. At the time of our visit the manufacture of the deep-sea section of the third Atlantic cable for the Commercial Cable Company was being proceeded with in the cable shop, where the members had the opportunity of inspecting this interesting process. The rate of working of the cable machines is about five nautical miles of deep-sea cable per machine per twenty-four hours.

It will thus be seen that we had a most interesting and instructive session, which remark applies equally to the vacation visits. Before leaving this subject I wish to impress upon the members the desirability, both in their own interests and in those of the Society, of preparing and reading papers, and of attending the visits. None but those who have read papers can tell how useful a work it is to themselves, for both in preparation and discussion they obtain a large amount of information which they would not otherwise acquire, whilst the practical value of visits to engineering works is beyond all question. It is to our late honorary secretary and treasurer, Alfred Williams, that the Society is indebted for the institution of these visits, and let us do all we can in memory of our late esteemed friend to encourage and perpetuate them.

Turning next to matters of more general interest, I would first observe that railway progress has been almost at a standstill, except as regards short branch lines, to relieve street traffic in congested districts. The question of locomotion governs the construction of these lines of railway, and is an important factor in their development. The City and South London Electric Railway having proved equal to the requirements of the public, and I believe remunerative to the shareholders, has opened up enterprise in this direction, and may fairly be said to have led to the construction and electric propulsion of the Liverpool overhead railway. In this case steam locomotive traction was out of the question, owing to the proximity of the line to the docks and wharves. As the railway traverses the whole length of these magnificent buildings, sparks from a boiler furnace might produce disastrous results. The facilities afforded by this line to business people have been fully appreciated ever since the line has been opened, and the success of this railway has no doubt led to the proposal to connect the London and South-Western Railway at Waterloo Station with the City by a line to be worked by electric traction. This will prove a work of unusual interest to engineers, and we may look forward to the prospect of making a visit of inspection probably during the next vacation. The work has already been commenced, and a large platform has been erected on the Surrey side of the Thames, similar to the one at the Swan Pier, London Bridge, which was used during the excavations of the tunnel under the Thames for the City and South London Electric Railway. The new line from Waterloo to the City will have an unbroken continuity of more than a mile and a half, and it will enter into keen competition with the omnibuses. Passengers will alight at the end of Queen Victoria Street, in the heart of the City, thus making Waterloo more convenient than London Bridge or Cannon Street. The new line will pass by an easy curve diagonally under the river, and this curve will give a starting impetus to the trains in either direction. This, with electrical motive power, will enable a speed of twenty-two miles an hour to be maintained. The speed of the trains of the Metropolitan Underground Railway averages about eight miles per hour. Other benefits are contemplated to relieve the street traffic at the City terminus by constructing a circular subway, surrounding the central underground station. The circular subway will have its floor ten feet below the present surface, and will be eight feet in height, with two feet thickness of roof above it. By it passengers will enter the subway without being exposed to the dangers of crossing the busy thoroughfares. The construction of the new electric line is being effected by a special company fostered by the South-Western Railway Company. The works are being carried out under the joint engineering control of Mr. Galbraith, of the South-Western Railway, and Mr. Greathead, who designed and constructed the City of London and Southwark Electric Line.

The mode of construction will be the same as that so successfully carried out on that line. The tunnels will be formed of iron rings in segments, flanged and bolted together, and the flanges will be planed to a smooth surface. For making up outside the cast-iron culverts, cement will be blown in through holes specially made, so as to produce a ring of concrete, forming an exterior skin. The space inside the culverts between the flanges will also be filled in with concrete, thus making a smooth and even surface through the tunnel. The diameter of the culvert will be 12 feet, except at the stations, where it will be increased to 12 feet 9 inches. The contract for the two parallel tunnels has been let to Messrs. Mowlem & Co., of Westminster. Caissons have been sunk under the staging at Blackfriars bridge, and as soon as the floor depth of the tunnel (69 feet) is reached, the four protecting shields and the mechanical excavators will be lowered into position, and the driving of the tunnels will be commenced in both directions. The geological formation in which the tunnel will be made is London clay, except at one place at Stamford Street, where a deposit of gravel will have to be passed, and will no doubt require air pressure to keep back large volumes of water, as was the case at Stockwell, on the Southwark line. The generating station will probably be at Waterloo station. It has not yet transpired what system of locomotion will be adopted, that is, whether electric locomotives will be employed, or whether motors will be attached to the carriages themselves. The consideration of the nature of the traffic will underlie the decision in this direction; it will have to be determined whether long trains or short ones will be necessary. On the Liverpool overhead railway two carriages are run, each capable of carrying sixty passengers.

The subject of inland navigation has during the past year attracted the attention of the engineering profession by a great conference at Belgium. The question at issue is whether canals should be placed in competition with railways, and to assist the agriculturist this point must be decided by those interested. At present the railway companies largely own both properties, having safeguarded their interests by purchasing the canals, the proprietors of the latter at the time willingly disposing of their property, anticipating ruin from the rival system.

One of the most important developments of canal engineering was open for traffic last year. This is the Manchester Ship Canal, which was opened by Her Majesty the Queen in person on May 21st, 1894, when the greatest modern engineering undertaking for water carriage was brought to a successful issue. Mr. Leader Williams was the chief engineer of the canal company.

The new lock and weir works and foot bridge at Richmond, Surrey, which was opened by H.R.H. the Duke of York on May 19th, 1894, was so ably and fully described by our immediate past President, Mr. Goodwin, that it only remains for me to record the great success of the undertaking. The experience gained after five months' working of the sluices has proved what was expected by all concerned in advocating the adoption of Mr. Stoney's invention, namely, that a grand sheet of water is provided four and a half miles in length with an increased depth of five feet. That part of the river between Richmond and Teddington Lock is thus rendered available for business and pleasure at all times of the tide.

Since the erection of the new lock and bridge the contrast between the aspect of the river above Richmond and the shoals and mud banks at Kew, Chiswick and Hammersmith has excited the attention of the inhabitants of the latter towns. Above the lock the scenery has been essentially beautified, pleasure traffic increased, and the value of property improved. Hammersmith has taken the initiative in seeking a remedy, and the local authorities of Putney, Fulham, Mortlake, Barnes, Chiswick and Brentford have agreed that something ought to be done to improve the river below Richmond Lock, and there appears to be a desire to construct a second half-tidal lock at Putney or Wandsworth, the representatives of which towns urge the gravity of the situation.

The Tower Bridge was so ably described by Mr. J. W. Wilson, jun., in his presidential address, 1892, who gave minute details of its construction from the commencement in 1886, that I need only refer to the successful completion of that great undertaking and the opening of the bridge for traffic by H.R.H. the Prince of Wales on June 30th, 1894. Mr. J. Wolfe Barry, the designer and engineer, must take credit for originality in this most unique construction for crossing a river without sensibly interfering with its enormous shipping traffic. The Tower Bridge has proved beyond all doubt a great relief to the congested traffic in the vicinity of London Bridge, and is one more evidence of the engineer's skill in providing facilties for bridging over difficulties and providing means for the expansion of our commerce with the world. The time occupied in the construction of these works was eight years, and the total cost was 1,195,000*l.*; the estimate being 750,000*l.* The annual cost of maintenance and repairs is 6000*l.*

However much the Tower Bridge will relieve the traffic of London Bridge and assist both sides of the river for some distance down, the fact remains that as that distance increases the necessity for a further means of communication between the shores also increases; the Tower Bridge being of no use to the inhabitants of Poplar as regards the opposite bank of the river. That fact has been recognised by the conception and carrying out of the new tunnel under the Thames at Blackwall, which is now in course of construction. The history of this tunnel dates back to 1879, when the late Metropolitan Board of Works first submitted a scheme to Parliament for connecting the two opposite sides of the river at that point. Passing by this and other projects, we come to 1887, when a bill was passed authorising the Metropolitan Board to construct a tunnel at Blackwall. Messrs. S. Pearson & Son, who are the contractors for the present tunnel, tendered for the 1887 scheme, the amount of their tender being about 320,000*l.* The proposed tunnel was merely a subway for foot passengers, but such as it was it would have been constructed had not the Metropolitan Board ceased to exist. The new authority, the London County Council, saw the opportunity for inaugurating a work of great public utility, and after consulting Mr. Wolfe Barry, Sir Benjamin Baker and Mr. Greathead, the present scheme was worked out by Mr. Binnie, the engineer to the County Council. The tunnel will be for the accommodation of vehicular traffic as well as that of pedestrians. Messrs. Pearson & Son again tendered for the work, the amount being 871,000*l.*, and their tender was accepted by the County Council.

The tunnel, which will unite the Middlesex and the Kentish shores of the river at Blackwall, commences at Northumberland Wharf in the former county and finishes at Ordnance Wharf in the latter. It is being constructed by a combination of methods which unite the use of the shield, cast-iron segments and compressed air at an average pressure of 24 lb. per square inch. When finished it will constitute the largest work of the kind carried out with this combination. It will be 24 feet 3 inches inside and 27 feet outside, with a clear air space of 17 feet 7½ inches between roadway and roof. It will have a roadway 16 feet wide for a double line of vehicles, flanked on each side by a footpath 3 feet 1½ inches wide. Under the bed of the river the tunnel will be on the level. The length of the cast-iron lined portion will be 3083 feet, while the cut-and-cover portion, which consists of brickwork and concrete, will be 1382 feet long. There will be open approaches flanked by retaining walls adding 1735 feet more, so that the entire length of the work from one entrance to the other will be 6200 feet. The gradients of the approaches on the north side will be 1 in 34, and that of those on the south side 1 in 36. The work of construction is progressing most favourably considering the variable nature of the stratification passed through, which includes a clay, gravel, sand drifts, &c. Such strata add greatly to the difficulties of carrying out this undertaking, especially when it is stated that the roof of the tunnel will be within about 8 feet of the river bed. And here I must express my thanks to Mr. Binnie for allowing me to inspect the plans and sections of the tunnel and for affording me information as to this important public work. Mr. Binnie informs me that the total length completed under the river was 722 feet 6 inches up to January 2nd, 1895.

Turning to water supply, I may observe that Liverpool is to be congratulated upon having obtained a plentiful supply of water from Lake Vyrnwy, in Montgomeryshire, Wales. She will now be out of her difficulty in this respect, having for several seasons previous to the completion of the aqueduct tunnel (alluded to in Mr. Wilson's address, 1892) had to restrict the water supply to the inhabitants during the summer seasons; but Liverpool, like Manchester, can now look forward to an inexhaustible water service so long as there is a moderate rainfall.

The scheme for the Manchester water supply was prepared by the late Mr. F. F. La Trobe Bateman, F.R.S., in conjunction with Mr. G. H. Hill, C.E., who, after the death of Mr. Bateman on June 10th, 1889, carried out the whole of the work on behalf of the corporation. The natural level of the lake was 533 feet above sea level, but when the level is raised to its full extent some 50 feet must be added. With this depth the length of the lake will be more than 3½ miles. The drainage area (including 3600 acres to be diverted into the lake) is 11,000 acres. The area of the lake itself in its natural state was 330 acres. Raised 20 feet (representing a supply of 10,000,000 gallons per day) the area is increased to 565 acres, with a capacity of 2534 million gallons, while if raised to the full height of 50 feet the area will be 793 acres, and the capacity 8135 million gallons.

As compensation for loss of water owing to the addition to drainage area, 4,126,125 gallons per 24 hours must be discharged into St. John's Beck; this is to be increased to 5,520,487 gallons when the lake is fully raised. The level of the lake is raised by means of two embankments, each 857 feet in length and 18 feet 6 inches in width. Their greatest height from foundation is 104 feet 6 inches. When the water level is fully raised, the tops of the embankments will be 6 feet 3 inches above the level of the lake. The flooding of the valley covered several roads, and this necessitated the construction by the corporation of some 9 miles of new roads. The water is carried from Thirlmere to Prestwich new reservoir, a distance of nearly 96 miles, by means of aqueducts and steel pipes, as follows:—Tunnels, 14⅛ miles; cut and cover, 36¾ miles; piping, 45 miles (for 10 million gallons per day). The rainfall is exceptionally large, ranging as it does from 52 to 137 inches per annum.

Birmingham has now definitely decided in favour of a gravitation scheme, and has already commenced supplementing the present water supply by a similar grand scheme to that just completed for Manchester.

Edinburgh is also contemplating the adoption of a similar scheme to that of the other large towns, namely, a gravitation supply. This is no doubt rendered necessary by the increase of population and the growing requirements of the improved system of sanitation.

Leicester, although like the towns already referred to, having a gravitation or lake supply, has during the past summer been put to the greatest inconvenience owing to the want of rain, the water storage there evidently being too limited for the growing requirements of the town. The present storage capacity of the reservoirs is 889,000,000 gallons of water, and at the average consumption of 17 gallons per head of the population, which is the average quantity when the water has been turned on 24 hours per day, is capable of supplying a population of 235,000 persons. The population at present supplied with water is estimated at 206,480. In the year 1890, the corporation went to Parliament for powers to acquire land and raise capital for an additional storage reservoir, to hold 550,000,000 gallons. These works are in course of construction, and when completed the corporation will have, with an average rainfall, a water supply equal to the demand of a population of over 300,000. The rainfall in the district averages 28 inches, and in the year 1891 the rainfall amounted to about 32 inches, in 1892 it was slightly under 23 inches, and in 1893 slightly under 22 inches. In 1894, up to August 4th, it was only 15½ inches. The corporation on finding the store of water rapidly diminishing, took steps to obtain an auxiliary supply from wells belonging to large mills in the neighbourhood; they themselves also sinking shafts for increasing the supply. With the experience thus gained, and after the severe drought of the past year, water engineers not only at Leicester, but also those of many other towns, will do well to look carefully into their sources of supply, whether the supply is taken from lakes or from springs deep seated in the earth. Both systems suffer from a deficient rainfall, and it is now an anxious question with engineers how best to provide the necessary supply of water and to avert the danger of a water famine in our great and growing cities and towns, which depend for their very existence on an abundant water supply.

The Royal Commission on metropolitan water supply has completed its labours, and has presented a most exhaustive report on the present supply and future requirements of the metropolis; having called in and obtained the advice of the most experienced eminent engineers, geologists and scientists in the country. As might be expected on such an important inquiry, opinions differ as regards the most efficient and satisfactory means for insuring a constant and unfailing supply of uncontaminated water for the present population, and to meet all the possible requirements of the future. Some witnesses advocated the present available sources of supply from the Thames, the Lea and New River, supplemented by wells in the chalk. At the same time they advocated the construction of immense storage reservoirs in the Thames valley for the purpose of collecting the flood water in the rainy season to meet the additional wants of the future increase in population. The boldest and grandest of all the schemes proposed was to secure one or more of the large Welsh lakes so as to provide and secure for the greatest city in the world for all time the abundant supply of water necessary to the preservation of health to its millions of inhabitants.

Considerable interest attaches to the points brought out in the evidence taken before the Royal Commission just referred to, as regards the quantity of water used in London, and the probable requirements of the metropolis as estimated for the year 1931. The returns made by the eight London Water Companies to the water examiner in 1891 gave the daily consumption of 182,456,905 gallons. Five companies are authorised to draw 120,000,000 gallons per day direct from the river Thames, viz. the Chelsea, West Middlesex, Grand Junction, Lambeth, and Southwark and Vauxhall. In addition, the East London Company is authorised to draw 10,000,000 gallons, bringing up the total to 130,000,000. The East London and the New River companies between them took an average daily supply from the river Lea of 55,500,000 gallons. Thus we have the Thames and Lea rivers supplying the lion's share of water, they being drawn upon to the extent of 185,500,000 gallons per day. The Kent water company stands alone with a supply from wells in the chalk. The large quantity of water required for our daily wants is found, practically speaking, at the very doors of the consumers, almost at the four points of the compass. The question that is now uppermost in the minds of those responsible for the health of the great metropolis is, how long the present main sources of supply—that from the rivers—can be drawn upon with safety. Towns are springing up where only villages once existed, and every year the water companies report a large increase in the number of connections with their several mains. Steadily and surely London is advancing along the river banks towards Kingston. The pretty little suburban towns of bygone years which are nearest to London have been found too urban, and City men, with the facilities provided by the railway companies, now travel to the villages surrounding the present intakes of the water companies. There is not the slightest doubt that, as the pioneers of water supply had in years past to move higher up the river on account of building operations crowding in the works, so in time it will become necessary to beat a still further retreat. At the present time, however, the water supplied from the rivers is found to be, by efficient filtration, wholesome and practically free from pollution, the health report being likewise satisfactory—London being the healthiest of all our large towns. All this goes to prove unmistakably that there is no immediate danger.

Then why should we be disturbed in our minds about the future when everything is progressing so favourably now, while recent droughts almost unprecedented have proved beyond doubt that the resources of the metropolitan supply are equal to the demand? The answer is that we have one exception which must compel us as water providers to look ahead, and that exception is Leicester with its recent water famine. Water, although looked upon in this country as the commonest of the necessaries of life, is not really sufficiently valued until the supply runs short, and yet it is one of the elements not so easily procured in certain localities when the rain falls short of the average, especially for two or three years in succession. When we take into consideration that the development of a new and reliable source for a large population may take from twelve to fifteen years to accomplish, it behoves us to be at all times in advance of the existing available supply. We must remember that Liverpool had to restrict her consumption long before the present magnificent service was available from Wales; and Manchester, again, commenced to develop her new supplies years before the water was actually needed. This has been the principal reason for the question being opened up by the London County Council in order to provide for future contingencies; and when it is considered (as estimated by those engineers conversant with the matter) that in the year 1931, provision must be made to supply 294,000,000 gallons per day to meet the requirements of the estimated increase in the population, it will be seen that the means of providing this enormous daily supply must be taken into consideration and the problem solved without delay.

At the present time our metropolitan water engineers are engaged in constantly increasing and enlarging their works. Those taking the bulk of their supply from the Thames and Lea being restricted as regards the quantity to be extracted, have judiciously opened up the gravel beds overlying the London clay with encouraging results, and so long as building operations do not intrude within reasonable distance of these new sources and contaminate them, all will be well. These works, however, are situated in some of the most picturesque spots on the Thames, and therefore cannot be long sacred from the speculator and builder. Other water engineers have been and are now sinking wells and driving adits in the chalk strata, some with good results, where the outcrop of the chalk was favourable. Our past President, Mr. Valon, treated this subject very fully in his inaugural address, 1893, and he especially dwelt upon the Kent Water Company, this being the only metropolitan company taking its entire supply from wells in the chalk, and expressed a strong opinion as to the possibility of getting a very large increase from this source to meet the growing requirements of the other metropolitan companies. With regard to the Kent Company we must take into consideration that their works are in a most favoured position, on the outcrop of the chalk on the south-east of London, with open country right into the water-bearing strata of Kent.

With regard to the progress made by other London companies for increasing the present supply of water for the ever-increasing consumers, the New River has in use ten wells, with others not yet in use, with a natural spring at Chadwell. The engineer of the East London Water-works (Mr. Bryan, M.I.C.E.) has been busily engaged for some years in sinking wells and driving adits in the chalk at Lea Bridge and neighbourhood to supplement the river water supply. Through the courtesy of Mr. Bryan I have been able to inspect two of these wells, namely, those at Lea Bridge and Walthamstow. Although these wells are within the area of the London clay, the floor of the adits being within 200 feet of the surface of the ground, they are fortunately sufficiently near to the outcrop of the chalk to ensure success, and are yielding over 3,000,000 and 4,000,000 gallons respectively. Other wells in use in connection with these works are giving even better results, and I am informed that additional wells are now in progress and other great additions are being made for storage and filtration. The East London Company is, as regards consumption, the largest of the eight metropolitan companies, heading the list in 1891 with a net daily supply of nearly 40,000,000 gallons, whereas the Kent Company, whose supply is taken entirely from wells in the chalk, had to provide but 12,500,000 gallons per day. Taking into consideration the fact that the water level in the chalk has been sinking at the rate of one foot per annum during the past 40 years, what must the result be when more water is abstracted from this source of supply? This steady and absolute reduction in the chalk water level must certainly be taken into account in calculations for the future. In some operations very large fissures have been intercepted in the chalk, notably in the Lea Valley. Whether these exceptionally large fissures are in direct communication with the neighbouring streams is a question time alone can answer. Long experience in dealing with chalk wells has shown that those deriving a supply from what is usually termed the bleeding of the chalk, and from the ordinary faults and fissures, gradually but surely exhaust the area drained in the course of a few years, and at very regular intervals the water engineer finds it necessary to tap fresh ground by extending the adits. The late Mr. Topley in his evidence before the Royal Commission is reported to have expressed the opinion when supporting Mr. Bryan's proposals for increasing the supply for the East London Water Company in the future, that there was something peculiar in the lower part of the Lea Valley which enabled it to yield an unusually large quantity of water. For instance, in the area above referred to one well with about 50 feet of adit yields 4,000,000 gallons per day, while another well, not far distant, yielded only about the same quantity of water, although tunnels have been driven over 7000 feet in length!

The Kent Water Company has been referred to with reference to what may be accomplished by sinking wells and the almost certain success in obtaining water from the chalk. Many wells in this stratum require an extension of the adits at regular intervals owing to the falling off in the yield. This should not surprise us when we take into account the additional number of wells being opened up and the increased quantity of water necessary to meet modern sanitary requirements. Not only are towns demanding more water, but villages are combining and adopting the same sanitary arrangements. The natural consequence is that the underground source of supply is being drawn upon to such an extent that slowly but surely the level of water is being lowered, especially where the fissures in the chalk depend upon saturation and are not in direct communication with surface springs or streams. This is the case at Richmond, Surrey, where great efforts have been made during the past 18 years to obtain a supply of water from the chalk, which is 254 feet below the surface of the ground. Here, the local authorities took upon themselves the responsibility of supplying the town with water, and at the commencement were advised to sink a well into the chalk and then to bore to a further depth of 150 feet. Should this not prove successful in yielding the required supply they were advised that adits should be driven.

Owing to an accident however—the cast-iron cylinders breaking just above the chalk—the latter alternative had to be abandoned. As resident engineer I suggested sinking a new well in order to carry out the plan as originally advised by the engineering experts, but upon the Local Authority consulting an engineer of great experience in well sinking, they were advised to sink a boring to a depth of about 1000 feet to the lower greensand, and this course was decided upon. This boring was continued to a depth of 1446 feet into the red sandstone, and proved the absence of the lower greensand, and only improved the supply from the great oolite by 15,000 gallons per day. It was then decided that this boring should be stopped, and since its abandonment a new well—some 800 yards distant from the original well—has been successfully sunk by me 30 feet into the chalk. At a depth of 320 feet from the surface adits have been driven in all directions, principally N.E. by S.W., intercepting almost at right angles many fissures and faults in the chalk. At the close of last year 4657 feet of adits had been driven, the dimensions being 6′ 0″ by 4′ 6″. Some of the fissures intercepted continue to yield the same quantity of water as when opened out, but many give out after a time as already mentioned, necessitating tapping new ground. We have not yet obtained half the quantity of water anticipated, namely, 500,000 gallons per day.

We hear much of those wells in the chalk which have proved successful, and but little of the larger number that have proved failures. A knowledge of these latter often proves instructive to the engineer, and I have but little doubt that engineers who have experienced these failures will be of my opinion, that for water supplies to our largest cities and towns it will eventually be necessary to look elsewhere. This will probably be to some lake district where the rainfall is the heaviest and can be stored with more or less ease in reservoirs and in immense quantities, where there is also no danger of the contamination to which the rivers now supplying the bulk of our water in the vicinity of London or other large towns are subject. This suggestion, it must be admitted, is a bold one, and involves an undertaking which must of necessity be carried into effect by some central authority. Certain success, however, must be the result. River water can, if necessary, still be utilised for such purposes as road watering, sewer flushing, large garden supplies, &c., in the event of a dual system of mains being laid. This system has been adopted at Richmond for some years with economical and very beneficial results, especially the supply for extinguishing fires, the water being at a much higher pressure than can be obtained from the ordinary water mains.

After a supply of water has been obtained for the service of a town, the next most important consideration is its distribution and the prevention of waste. This is especially the case in those towns where there is only a limited quantity to distribute and where a supplementary supply of water has to be purchased from a neighbouring water company to meet the local deficiency, as at Richmond. There the Southwark and Vauxhall Company have made a connection between their large mains which pass through the town, and the corporation mains, thus relieving the resident engineer and the inhabitants of great anxiety in the event of accident or stoppage from other causes. Of all the necessaries of life water is considered by the great majority of people as the most common and of the least value, unless when measured by a meter. With reference to meters, engineers, like other professional men, differ in opinion, especially with respect to what should be a reasonable consumption per head per day to preserve the health of the locality. Mr. Binnie, chief engineer of the London County Council, is of opinion that 35 gallons per head is the least that should be estimated for the supply of large cities or towns. Dublin is reported to consume 47 gallons, Glasgow 50 gallons, and Edinburgh 40 gallons per head. On the Continent and in America the quantity far exceeds even these. With regard to the actual quantity required for domestic purposes, however, there is a general consensus of opinion that 15 gallons per head is sufficient. The average daily consumption per head of the London companies is estimated for all purposes at about 31 gallons, the lowest being the Kent Company, with 27·21, and the highest the Grand Junction, with 47·72. This exception is, I find, accounted for by reason of the plentiful supply of water available, the engineer of the Company having found it cheaper to pump water than supervise and control waste.

Water engineers can testify to the great cost of detecting waste both by house to house inspection and by the adoption of the waste-water meter system. For instance, at Richmond one waste inspector is constantly employed, besides which ten Deacon's waste-water meters are used at intervals. With this careful supervision the consumption of water may be considered reasonable for a suburb of London, in view of the proper domestic sanitary arrangements, and seeing that most houses from 35*l.* rental and upwards possess a bath, and that there are also public baths. The total consumption for 1893–94 averaged 26·4 gallons per head per day, the consumption for domestic purposes being only 18·3 gallons per head per day. This consumption compares favourably with other towns tabulated in the water-works statistics for the year 1894. Fifteen towns in England, Scotland, and Wales, not including London, have a consumption of from 75 to 40 gallons, and there are seven with from 12 to 8 gallons per head per day. Many of the former towns, especially in North Britain, use water largely for trade purposes. Between 12 and 8 gallons, however, is a low consumption; probably these towns have few baths, and water may not be much used for domestic sanitary purposes. These statistics would be of greater use for comparison if the engineers of water-works would state the population, and for what purposes the water is used other than domestic.

The question of the advisability of supplying water to consumers by meter was pretty well threshed out by Mr. Valon in his presidential address. There is certainly the danger of too small a consumption by this system (if universal) in a town, unless the sewers are thoroughly and regularly flushed with water by means of properly constructed chambers built at the extreme ends of all branches leading into the main sewer. The house drains might be sufficiently flushed by the addition of the rain water from the roofs of houses and the yards at their rear.

The next great objection to metering the supply to a town is the dealing with small property. Probably most cottage property owners compound for the water rate, and if these cottages were restricted to a certain reasonable allowance per day by throttling the service pipes, one difficulty would be surmounted. But we should still have to deal with other cottagers paying the water rate direct and using water for laundry work, and still others who are careless in leaving water running to waste. These consumers would prove troublesome in recovering the meter rents. With all these drawbacks, however, there is a growing demand by the larger ratepayers for being supplied by meter, especially in a town like Richmond, where no extra charge is made for baths, domestic sanitary arrangements, private horses and carriages, and where there is an extra charge for gardens only where water is actually used from the town supply. Those consumers, however, who do not possess baths or carriages naturally complain of having to pay for those using water for such purposes. I must admit there will be less inconvenience as regards the solution of this question under a corporation than by a water company. It is well known that small property does not pay, and the better-class property compensates for the loss before referred to.

The question of supplying water by meter is an old one, and numerous attempts have been made to produce a meter which will accurately register the consumption under all the varied conditions of daily use. Many of these attempts have proved futile, whilst in other instances success has attended the efforts of inventors, and water companies generally are availing themselves of the meter system where practicable. There can be no question that, as a broad and general principle, where an accurate register of the supply can be insured, the advantage both to the supplier and the consumer must be very considerable. On the one side the great point is the prevention of waste; whilst on the other it is most satisfactory to the consumer to know that he only pays for what he uses. The efficiency of certain meters has been so far proved by practical use that there can be no longer any excuse for not adopting the system where applicable. In support of this statement, as regards measurement on the large scale, I may mention that a 1½-inch meter in use at the Lambeth Water-works registered 31,835,000 gallons of water in 18 months. On testing the meter after doing this duty, it was found to be in excellent condition, and was replaced and continues in use. The net cost of measuring by meter is stated to be 1*s*. 3*d*. per million gallons.

As far as I am aware, all the meters at present in use, with one exception, have moving parts. That exception is the Venturi meter, which has recently come under notice in this country, and in which the measurement is obtained without any moving part whatever. It is a large volume instrument, and its action is based upon a law in hydraulics first established by Venturi in 1796. The applicability of this law to water measurement has been demonstrated by Mr. Clemens Herschel in the United States, by exhaustive experiments, which have established the absolute trustworthiness (under every conceivable condition) of the instrument into which the principle has been introduced. This law establishes the relations between the velocities and pressures of fluids when flowing through converging and diverging tubes. It demonstrates that water flowing through a reducing cone connected to an expanding cone introduced into a pipe line passes with practically no loss of head, although the neck of the cones is but a ninth part of the area of the main. At the same time a marked depression —increasing with the speed of flow—occurs at the neck. A meter on this principle therefore consists of two parts, namely, the tube through which the water flows, and the recorder which registers the quantity of water that passes through the tube. In its completed form it constitutes an instrument for gauging the quantity of water flowing in a pipe by measurement of an abrupt, artificially produced depression in the hydraulic gradient.

As recently described in the *Engineer*, the tube takes the shape of two truncated cones joined at their smallest diameters by a short throat-piece near the up-stream end, having at the throat and inlet branch orifices at which the pressures are taken, the use of which depends on the property which causes the pressure of the water flowing through the throat to be less, by virtue of its greater velocity, than the pressure at the up-stream and of the tube, each pressure being at the same time a function of the velocity at that point and of the hydrostatic pressure which would be obtained were the water motionless within the pipe. A recorder, which is connected with the tube by pressure pipes which lead to it from the chambers surrounding the up-stream end and the throat of the tube, records the flow of water, so that readings may be obtained in the ordinary way. It is operated in part by a weight, and in part by clock-work. The difference of pressure or head at the entrance and at the throat of the meter is balanced in the recorder by difference of lead in two columns of mercury in cylindrical receivers, one within the other. The inner one carries a float, the position of which is indicative of the quantity of water flowing through the tube. By its rise and fall the float varies the time of contact between an integrating drum and the counters by which the successive readings are registered. Usually the integrating drum revolves once in every ten minutes, and at each revolution the counter registers, on ordinary dials, the volume flowing for that period of time.

The Venturi meter is, of course, specially adapted for the measurement of water in trunk mains of any diameter from 6 inches to 6 feet. Registration can be effected by a counter as on an ordinary meter, or by diagram giving the rate of flow at any moment of time, or by both, and the indications can be conveyed by electric current to the engineer's office at any distance from the meter. At present there are only three of these instruments at work in England, but in America, where it was first introduced, there are between thirty and forty in use, several of which are said to be registering over 100,000,000 gallons per day. The main water supply to the World's

Columbian Exhibition was measured by a Venturi meter having a capacity of 30,000,000 gallons per day, the supply pipe being 36 inches in diameter.

Appended to this address are three tables, A, B and C, which I think will prove of value to water engineers. They form a portion of a paper read before the Corporate Treasurers' and Accountants' Institute at Hull, in June 1893, by Mr. W. Penn Lewis, F.S.A.A., F.S.A.

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The latter part of the past year has been marked by floods and storms, loss of life and serious damage to property having arisen from both these causes. The floods of November in the south-west of England were said to be the worst experienced within the memory of any one living in the district. Fortunately, the loss of human life was small, but heavy losses of horses, cattle and sheep occurred in Devonshire and the surrounding counties. So heavy was the downfall that railway traffic had to be suspended. Upon one occasion a train from Weymouth endeavoured to pass through a deeply flooded portion of the line near Yeovil, and was practically wrecked, owing to the water having washed away the ballast. Later on we had floods much nearer home, namely, in the neighbourhood of Windsor and Eton, the most serious flooding occurring at Datchet. Unfortunate as these occurrences are, we may congratulate ourselves upon the circumstance that we are not so badly off in respect of rain-storms as our neighbours in various parts of the Continent. There these visitations often flood hundreds of square miles of land, carrying everything before them. In England the south-western counties are probably the most liable to these visitations, because so many of the rain-bearing disturbances from the Atlantic make for the district, a triangular region, the interior of which is hilly country, where the higher elevations intercept the lower clouds, and so attract a deluging rain. The local rivers, which after all are nothing more than brooks, are utterly incapable of immediately conveying away to the sea any unusual quantity of water, and the consequence is that the low-lying lands are quickly submerged. Serious and extensive floods are the result not so much of the absolute quantity of the rainfall, but of the physical features peculiar to a district, and the want of sufficient facilities for carrying away any sudden downfall.

Before leaving the subject of rainfall, I may mention a circumstance which has just been brought under my notice on good authority. In Antigua the sugar-cane plantations have suffered from drought during the summer months, some crops having been practically destroyed. Later on in the year a little rain fell here and there, but the water supply was pretty well exhausted. Near the close of the year, however, a terrific storm burst over the island, and such was the downpour that in one night alone 12 inches of rain were registered. The water supply reservoir, which holds 12,000,000 gallons, was empty in the evening, but the next morning was found to be full, to the great relief of the population.

While on the subject of meteorological disturbances, it may be interesting to notice the new American observatory which has been established in South California by Professor D. S. C. Lowe. This observatory is seven miles by rail north of Pasadena, and sixteen miles north-east of Los Angeles. It is well equipped with a 16-inch Clark refractor and other instruments. The buildings consist of a central tower, 32 feet in diameter, surmounted by a light dome, and two wings, one being used for photographic work, and the other being set apart for the extensive astronomical library of reference formed by Dr. Swift. The Sierra Madre Mountains, upon which the Lowe observatory has been placed, have an east and west trend, and rise abruptly from the San Gabriel Valley to an altitude exceeding 6000 feet above sea level. The observatory is built upon the southern spur of these mountains, and its altitude is about 3600 feet above the sea. Astronomically it is nearly at the intersection of the 34th parallel of north latitude with the 118th meridian of longitude west of Greenwich. Besides having the advantage of an unclouded sky, there is a peculiar clearness in the atmosphere. Three-fourths of a mile of the densest portion of the atmosphere is below the observatory. Another advantage is the equable temperature of the mountain, which seldom descends to 40° F.

Accommodation for our ever-increasing maritime industry must claim the attention of our profession. The growing dimensions of our mercantile ships demand that docks of adequate proportions must be provided to accommodate them, and to facilitate loading, discharging and repairing the magnificent vessels now engaged in carrying on the commerce of the country. Soon after purchasing the Southampton Docks, the London and South-Western Railway Company set about improving the valuable property acquired by them in connection with their line. They now have in hand one of the largest dry docks in the kingdom, and they have built immense granaries for storing corn, and constructed a covered station, or landing place, alongside the dock, thus giving passengers from the ships the comfort of stepping from the ship into the train, and obviating the delay and discomfort of trans-shipping to a tender, thence by cab to the railway station, situated at a distance, as at Liverpool. There is no doubt the accommodation provided at the Southampton docks will prove remunerative to the shareholders of the railway company.

Liverpool appears to have awakened to a sense of her shortcomings and behind-the-times condition in this respect, and she is about to set her house in order. I learn that the Mersey Docks and Harbour Board has recently had before it a proposal by a committee to carry out a variety of works, in order to facilitate the transfer of passengers from transatlantic and other large steamships to the principal railway systems of the country, at a total estimated cost of 36,800*l*. The Waterloo goods tunnel, and the dock line of railways which partly traverse the streets, are to be utilised; certain bridges are to be strengthened, a passenger railway station at the pierhead is to be provided, and the river is to be dredged, so that the largest steamers can come alongside the landing-stage. This was proposed in order to enable the transatlantic liners to compete on more favourable terms with those of Southampton, and save passengers the inconvenience of having to cross the city in cabs. The scheme was unanimously approved, and the work will now be pushed on, with a view to its being completed by the opening of the next Atlantic passenger trade season.

Our coal production is a question which interests all very closely, whether they be producers or consumers of that most important article of our national industry. A few words, therefore, respecting it on the present occasion may not be out of place. The question was touched upon by our past President, Mr. Perry F. Nursey, in his inaugural address in 1886. He took up the theory of coal exhaustion and of the probability of our immediate descendants having to face a coalless England at no distant period, as propounded by Jevons, Playfair, Dewar and others. He dissented from their conclusions, and showed from his own personal observations that that event was constantly being relegated to more remote periods by fresh discoveries of coal. In the South Yorkshire coal-field alone, which he had visited a few years previously, he found over one hundred new collieries, which he located seriatim, had been started within a short time of his visit, and he referred to subsequent developments in South Wales and elsewhere. Although I have not followed the discoveries of coal since Mr. Nursey's address, I have seen by the papers what all the world knows to be the case, namely, that new workings have been opened from time to time, and that coal discoveries have taken place in other countries, whilst Continental resources, notably those of Belgium, have been further largely developed. This means relief to our home supplies, the cost of getting which naturally increases with the depth of the workings. In any case, I do not hold alarmist views with regard to our coal exhaustion being near at hand. Before that time arrives our descendants will doubtless have matured the means of meeting the exigency.

At the same time we should do our best to conserve our supplies.

Having touched upon the question of our future coal supply, my brief remarks thereon may be aptly supplemented by a few observations on the coal production of the world. These I make from some statistics which were published last autumn, and which show the enormous growth that has marked the production and consumption of coal throughout the world during the past forty years, as well as the changes in the production in different countries. In 1850 Great Britain produced more coal than all the rest of the world put together. Her recorded output was then somewhat more than 55,000,000 tons, the highest production in any other country being 6,000,000 tons. Our home production went on increasing until in 1890 it reached 188,000,000 tons, since which time the output has declined. It is true that strikes have of late had something to do with this decline, but the expense of mining coal is increasing, which practically means giving some of our export trade to other countries. As regards our consumption in 1851, it was 1¾ ton per head, and in 1892 it was 4¼ tons per head. Although marked by fluctuations the increase has been more pronounced than in any other European country. Belgium and Germany, however, show a nearly equal increase.

The United States comes next to Great Britain in respect of production, the increase in which, however, is much more strongly marked than with us. At the starting point the United States output was less than one-third that of Great Britain, but last year it had reached to within about 1,000,000 of our output, and there is every reason to expect that in a few years America will be the leading coal-producing country in the world. There is, however, a marked difference between the two countries now under notice as regards consumption. With America the consumption is nearly on a par with production, but with us it is far otherwise, as Great Britain is, and will for many years remain, the great coal exporting country of the world, assisting in supplying other European countries besides sending to her own colonies and to parts of Asia and Africa. As regards the colonies and Asia, however, the demand is decreasing as new and nearer sources of supply are found. The consumption in the United States, which in 1870 was a little over a ton per head, had advanced in 1890 to 2¼ tons.

Germany ranks third in respect of the production and consumption of coal, and at one time she ran the United States very close as regards production. She has, however, fallen behind since 1880, owing to her more limited resources and slower growth. In 1892 it was only 98,000,000 tons, whilst that of the United States was 164,000,000 tons. The German lines of production and consumption diverge considerably, the exports being large, especially to France and Austria. In France the consumption is far in advance of the production, as her coal-fields are comparatively limited and pretty thoroughly worked. A large deficit is made up by heavy imports, chiefly from Belgium and Germany. In Belgium and Austria the output of coal has been steadily increasing. In the former country it has kept up well to the limits of its capacity, which means that while consumption may possibly increase, production will begin to fall off, and she will have to meet a deficit by importing coal. The output in Russia has been steadily growing, and a large increase may be anticipated in a few years with the extension of railways in the direction of the extensive coal deposits which are known to exist in South-Eastern Russia and in Western Siberia, but which are not at present worked for the want of facilities of transport. South Africa, Australia, India and other smaller coal-producing countries all show an increased output. In Japan coal mining has received a check during the last two years, but in view of the persistent efforts of that enterprising nation to push their product throughout the East, this check can only prove temporary. In all probability Japan will be for many years to come the leading coal-producing country of the Far East, notwithstanding that coal is found in many Asiatic countries, and is believed to exist in large quantities in China.

Perhaps the most important circumstance bearing on the question of substitutes for coal is the discovery made by Mr. T. L. Wilson, of the United States, with respect to acetylene. This discovery was recently brought before the Society of Arts in a paper read by Professor Vivian B. Lewes. Acetylene is a combination of carbon and hydrogen, many properties of which have been known for some time past. It is stated that from it can be built up all the other hydrocarbons capable of being used for illuminating purposes. Besides heat and light, acetylene is said to be capable of producing the aniline dyes, and, what is more remarkable, certain alcoholic beverages without the aid of the grape or fermented grain. Mr. Wilson made his discovery while endeavouring, by the aid of an electric furnace, to form an alloy of calcium from some of its compounds. Fusing down in the electric arc a mixture containing lime and powdered anthracite, and not finding the result to be that which he was seeking, he threw the mass into a bucket of water. A violent effervescence of the water denoted the rapid evolution of a gas of strong odour, and which, on ignition, burnt with a smoky but luminous flame. Upon investigation it was found that a mixture of chalk or lime with carbon in any form could be fused in the electric furnace with the formation of calcic carbide, and that on the addition of water a double decomposition took place. The oxygen of the water combines with the calcium of the calcic carbide, forming lime, whilst the hydrogen unites with the carbon of the calcic carbide, forming acetylene, which is produced inexpensively, as any form of carbon may be used, whilst chalk is cheap enough anywhere. By this discovery we may be rendered independent of coal and oil, as Professor Lewes tells us that it places in our hands the prime factor by which nature, in all probability, produces those great underground storehouses of liquid fuel upon which the world is so largely drawing to-day. It is anticipated that as soon as the commercial production of calcic carbide has been established, it will be placed upon the market in the form of rods or cylinders. For use it will only be necessary to place the carbide in a suitable vessel and to allow water to slowly drip upon it, when the acetylene will be evolved in a continuous stream, the solid mass being converted into slaked lime.

With regard to the progress made during the past year with electric lighting, I think some reference to a new danger in our streets would not be out of place. I refer to the explosions which have occurred of late in the subways carrying electric cables in the Euston Road, Cannon Street, at the Haymarket and on Southwark Bridge. Happily these accidents have not been attended with loss of human life ; but the number of almost marvellous escapes would tend to show that these electric subways constitute a real and growing danger to the public. There is a difference of opinion amongst the responsible parties as to the cause of these explosions, but there can be little doubt that in most instances they were caused by a leakage of coal gas into the subways, the gas being fired by a spark from the electric cables that had from some cause or other become short-circuited. Doubtless some action to prevent a recurrence of these explosions will be taken by the Board of Trade upon the reports submitted to them by their inspectors.

In conclusion, I would observe that the question of the education and training of engineers, although so often brought to the front, still claims the attention of the Society. It is a matter of great importance to the profession in these days of competition, especially with other nations, some of which are reported to be far in advance of us as regards technical education. It must be admitted that almost a craze has of late set in in this direction, and the question arises whether the academy shall take the place of the workshops, and our junior engineers be turned out ready made direct from school. It was not so in times past, most of our early and successful engineers having been men of little theoretical education, but of early and hard-headed practice. At the present time our juniors have every facility afforded them of obtaining a liberal education, and there is every inducement for the young shop apprentice to obtain knowledge in the higher branches of science at evening classes, thus combining a thorough understanding of practical work with theoretical instruction. By this means an engineer is qualified to undertake a position of responsibility, and is especially suited to the work of our colonies when called upon to utilise unskilled labour.

I question whether some of our young engineers are doing the correct thing in following the present course of professional education. They serve but a short time in works, and at an age when the handling of tools and the work performed is not of an enticing nature, and I doubt whether they obtain a sufficient knowledge of the practical part of the profession to fit them for the work required of them to make the undertaking with which they are connected pay, which is the all-important point. Some time ago there was a series of articles in the *Engineer* upon the training of engineers, and with reference to some sent abroad as executive assistant engineers it was stated that when called upon to undertake duties with the aid of native unskilled labour they, being themselves without sufficient every-day practical knowledge, were at a disadvantage as compared with a thorough practical man who had gone through the mill and who had devoted much time to the details of his work.

One illustration of my point which has come under my notice will be useful. It is that of a young man well educated and who could converse and write in three languages. He was, moreover, healthy and strong, and having a great desire to become an engineer was duly articled for three years, with a good premium. On completing his term he could not obtain employment, being neither proficient as a workman nor fit to direct, so he wisely donned the shop clothes and entered another works as a labourer, starting work at 6 a.m. At the same time he took evening lessons in mechanical drawing. Education combined with practical knowledge won in the long run, as it always must, and, with steady perseverance added, the essential qualities in the pupil referred to were in due time recognised. To sum up the matter, I desire to point out that in these days when the profession is so crowded with workers it is more than ever necessary for the rising generation of engineers to be thoroughly educated in every sense of the word for their important and responsible calling. Whilst acquiring the higher branches of knowledge they should work shoulder to shoulder in the shops with the class of men whom they may one day have to direct and control.

TABLE A.

Corporation.	Population supplied with Water.	Rateable Value of District of Supply.	Loan indebtedness for Waterworks.	Burden of Loan indebtedness.	
				Per head of Population.	Per Pound of Rateable Value.
1.	2.	3.	4.	5.	6.
		£	£	£	£
Barrow-in-Furness.. ..	65,000	322,831	170,099	2·6169	0·5269
Bath	61,800	382,246	68,900	1·1149	0·1803
Batley	28,719	90,782	313,676	10·9223	3·4553
Blackburn	123,000	440,000	715,000	5·8130	1·6250
Bolton	260,000	900,000	763,307	2·9358	0·8481
Bradford	450,000	1,610,000	2,179,420	4·8432	1·3537
Brighton	150,000	988,000	496,167	3·3078	0·5022
Burnley	93,000	310,000	233,052	2·5059	0·7518
Cheltenham	43,000	248,752	321,812	7·4840	1·2937
Croydon	85,000	398,500	105,435	1·2404	0·2646
Doncaster..	32,000	160,191	146,000	4·5625	0·9114
Exeter	40,000	220,000	131,000	3·2750	0·5955
Gloucester	41,050	160,000	55,070	1·3415	0·3442
Hastings	52,223	360,807	84,826	1·6243	0·2351
Hereford	20,000	75,000	6,500	0·3250	0·0867
Huddersfield	141,000	571,000	990,399	7·0241	1·7345
Hull	204,750	757,471	217,740	1·0634	0·2875
Leamington	26,930	168,100	24,154	0·8969	0·1437
Leicester	197,135	700,000	569,733	2·8901	0·8139
Lincoln	50,000	149,978	90,000	1·8000	0·6001
Manchester	963,550	4,966,623	4,773,225	4·9538	0·9611
Northampton	70,000	191,500	330,000	4·7143	1·7232
Oldham	208,145	895,000	816,881	3·9246	0·9127
Plymouth..	90,000	320,000	102,239	1·1360	0·3195
Reading	65,000	300,000	150,000	2·3077	0·5000
Richmond (Surrey) ..	23,000	180,000	50,258	2·1851	0·2792
Rochdale	110,000	450,000	828,480	7·5316	1·8411
Rotherham	44,000	142,771	136,534	3·1031	0·9563
Scarborough	32,088	184,106	201,722	6·2865	1·0957
Sheffield	338,000	1,178,678	2,166,568	6·4100	1·8381
Shrewsbury	27,000	130,000	30,000	1·1111	0·2308
Southampton	65,800	266,000	127,282	1·9344	0·4785
Swansea	100,000	330,000	425,000	4·2500	1·2879
Wigan	36,000	175,094	134,389	3·7333	0·7675
Worcester	40,000	150,000	13,213	0·3303	0·0881
	4,377,190	18,873,430	17,968,081	4·1049	0·9520
Birmingham	570,000	Cannot be stated.	2,215,000	3·8860	..
Derby	103,500		359,130	3·4699	..
Halifax	200,000		650,000	3·2500	..
Liverpool..	800,000		4,650,000	5·8125	..
Wolverhampton	131,000		262,074	2·0006	..
Gross Totals	6,181,690	..	26,104,285	4·2228	..

TABLE B.

Corporation. 1	Annual Income. 2	Annual Expenses. 3	Proportion of Annual Expenses.		Water supplied per Annum.		Average Quantity of Water supplied per head per day. 8	How Water distributed (see Note A.) 9
			Per head of Population. 4	Per £ of Rateable Value. 5	Quantity (in 1000 Galls.) 6	Cost per 1000 Galls. 7		
	£	£	£	£		£	galls.	
Barrow-in-Furness.	17,636	13,800	0·2123	0·04275	787,795	·01752	33·205	(*a*)
Bath	13,400	10,000	0·1618	0·02616	475,000	·02105	21·058	(*a*)
Batley	15,827	16,169	0·5630	0·17811	360,000	·04491	34·343	(*a*)
Blackburn	34,000	35,356	0·2874	0·08036	1,186,250	·02981	26·423	(*a*)
Bolton	52,060	40,468	0·1556	0·04496	1,921,282	·02106	20·246	(*a*)
Bradford	118,218	123,841	0·2752	0·07692	3,650,000	·03393	22·222	(*a*)
Brighton	45,000	38,000	0·2533	0·03846	2,000,000	·01900	36·530	(*b*)
Burnley	16,000	15,900	0·1710	0·05129	700,000	·02271	20·622	(*a*)
Cheltenham.. ..	16,935	17,000	0·3953	0·06834	292,000	·05822	18·605	(*c*)
Croydon	20,000	17,000	0·2000	0·04266	1,000,000	·01700	32·232	(*b*)
Doncaster	7,500	7,800	0·2438	0·04869	Not stated			(*a*)
Exeter	11,600	11,600	0·2900	0·05273	Not stated			(*b*)
Gloucester	7,135	6,146	0·1497	0·03841	220,000	·02794	14·683	(*a*)
Hastings	11,359	15,805	0·3026	0·04380	347,000	·04555	18·204	(*b*)
Hereford	4,500	2,550	0·1275	0·03400	212,000	·01203	29·041	(*b*)
Huddersfield ..	49,893	45,986	0·3261	0·08054	1,274,000	·03610	24·755	(*a*)
Hull	36,023	24,670	0·1205	0·03257	2,936,000	·00840	39·286	(*b*)
Leamington ..	3,800	4,000	0·1485	0·02380	208,880	·01915	21·250	(*b*)
Leicester	47,888	36,661	0·1860	0·05237	1,301,743	·02816	18·091	(*c*)
Lincoln..	9,185	8,385	0·1677	0·05591	445,000	·01884	23·484	(*b*)
Manchester	236,511	245,222	0·2545	0·04937	8,803,596	·02785	25·032	(*a*)
Northampton ..	20,150	20,350	0·2907	0·10627	300,000	·06783	11·742	(*c*)
Oldham..	53,230	52,000	0·2498	0·05810	1,400,000	·03714	18·428	(*a*)
Plymouth	14,500	*5,000	**0·1611	**0·04531	1,642,500	**·00883	50·000	(*a*)
Reading	14,000	12,000	0·1846	0·04000	754,442	·01591	31·799	(*b*)
Richmond (Surrey)	10,600	10,500	0·4565	0·05833	208,000	·05048	24·777	(*b*)
Rochdale	28,675	36,420	0·3311	0·08093	600,000	·06070	14·944	(*a*)
Rotherham	9,520	8,897	0·2022	0·06232	393,724	·02260	24·516	(*b*)
Scarborough ..	12,995	13,012	0·4055	0·07068	374,000	·03479	31·933	(*b*)
Sheffield	101,679	99,537	0·2945	0·08445	2,400,000	·04147	19·454	(*a*)
Shrewsbury	5,000	4,333	0·1601	0·03333	365,000	·01187	37·037	(*b*)
Southampton ..	..	13,070	0·1986	0·04914	875,000	·01494	36·433	(*b*)
Swansea	16,000	25,080	0·2508	0·07600	949,000	·02643	26·000	(*a*)
Wigan	10,500	10,240	0·2844	0·05848	350,000	·02926	26·636	(*b*)
Worcester	6,750	6,130	0·1533	0·04087	510,000	·01202	34·932	(*b*)
	1,078,069†	1,052,928	0·2406	0·05579	39,242,212‡	·02634‡	24·973‡	..
Birmingham ..	144,541	141,509	0·2483	(*d*)	6,111,000	·02316	29·373	(*b*)
Derby	24,749	19,195	0·1855	(*e*)	720,000	·02666	19·059	(*b*)
Halifax..	44,425	39,380	0·1969	(*f*)	1,500,000	·02625	20·548	(*a*)
Liverpool	241,400	241,400	0·3018	(*g*)	7,200,000	·03353	24·658	(*c*)
Wolverhampton ..	26,158	25,252	0·1928	(*h*)	1,178,000	·02144	24·637	(*b*)
Gross Totals ..	1,559,342†	1,519,664	0·2458	..	55,951,212‡	·02681‡	25·090‡	..

Note A, Col. 9:—(*a*) Gravitation (*b*) Pumping. (*c*) By both methods.
(*d*) (*e*) (*f*) and (*h*) Apparently about £0·6 per £. (*g*) Apparently about £·04 per £.
* Plymouth—Repairs and Salaries only. ** Proportion of Income.
† Exclusive of Income for Southampton.
‡ Exclusive of quantity and cost for Doncaster and Exeter.

TABLE C.

CORPORATION.	Rate or Rent in the £ for Domestic Supply (Dwelling-houses only).	CHARGE BY RATE, RENT,			
		W.C.'s.		Baths.	
		First.	Others.	First.	Others.
Barrow-in-Furness	*1s. under 50l.; 9d. over 50l.	..	5s. above two	6s.	..
Bath	†Under 8l. 10s., 8s. per ann.; over, 5 per cent. to 2¼ per cent.	..	..	..	..
Batley	†1s. 6d.	..	7s. 6d.	10s.	..
Birmingham	†6 per cent. (average)	..	4s.	6s. to 10s.	..
Blackburn	†8 per cent. over 8l. per ann.; below, min. of 13s. per annum	Includes use of	W. C. and bath, Bath for houses	and an additional above 40l.	W. C. and
Bolton	*1s. 4½d. to 9½d.	10s. each first two	3s.	5s. each first two	3s.
Bradford	†1s. 6d. to 1s.	3s. to 12s.	3s.	3s. to 12s.	3s.
Brighton	†9d.	¶	¶	¶	¶
Burnley	*1s.	..	10s.	10s.	..
Cheltenham	*Cottage min. 8s. 8d. per ann.; 6 per cent. to 20l.; 5 per cent. above	..	..	20s.	..
Croydon	†4d. plus 5s. per house to 12l., and 8s. above	..	..	..	..
Derby	*1s. 4d. to 7⅕d.	4s. to 12s.	2s. to 6s.	4s. to 12s.	2s. to 6s.
Doncaster	*1s. 6d.	¶	¶	¶	¶
Exeter	†1s.	¶	¶	¶	¶
Gloucester	*10d.	..	..	..	..
Halifax	*1s. 3d. to 9½d.	¶	¶	¶	¶
Hastings	†8d.	¶	¶	¶	¶
Hereford	†1s. 4d. to 8½d.	..	..	..	..
Huddersfield	*2s. to 1s. 3¼d.	..	5s.	10s.	5s.
Hull	*1s. 3d. (max.), and reducing scale	In offices, &c.,	21s. each ‖	10s.	..
Leamington	†4s. up to 6l., R.V.; above 10d. (max.), and reducing scale	Where house not supplied 10s. each.		..	..
Leicester	†1s. 3⅓d. to 10⅘d.	4s. to 6s.	2s. to 3s.	4s. to 8s.	2s. to 4s.
Lincoln	†1s.	..	10s.	10s.	..
Liverpool	†7½d.	..	..	..	..
Manchester	†9d.; and 3d. on all property for public supply	..	..	10s.	..
Northampton ..	†1s. 6d.; ‖10s.	2s. and 6s. each	..	6s.	..
Oldham	*1s. 6d.	..	..	..	..
Plymouth	*1s. 2⅖d., and reducing scale	..	..	..	..
Reading	*4 per cent. to 4½ per cent. ..	4s. to 12s.	2s. to 6s.	..	..
Richmond (Surrey)	†1s.	..	..	..	..
Rochdale	†10 per cent. to 7 per cent. ..	6s. to 20s.	..	6s. to 20s.	..
Rotherham	†7 per cent.; ‖6s.	..	5s.	5s.	..
Scarborough	†1s. 1d.	10s.	5s.	10s.	5s.
Sheffield	†15½ per cent. to 3¾ per cent.; ‖8s. 11½d. per ann.	5s. to 12s. 6d.	5s.	4s. to 16s.	..
Shrewsbury	†6 per cent.	¶	¶	¶	¶
Southampton ..	†1s.	..	..	..	..
Swansea	*5½ per cent.	¶	¶	¶	¶
Wigan	†1s. 3⅗d. to 8$\frac{7}{10}$d.; ‖13s. ..	..	..	..	..
Wolverhampton ..	†6¼ per cent.	10s. each	..	..	..
Worcester	†7d.	..	..	..	..

* On Rental. † On Rateable Value. ‡ By Meter only. § By Agreement only.
‖ Minimum Charge for Year.

TABLE C.

OR AGREEMENT.						METER SUPPLIES.
Garden Supplies.	Garden Hose.	Fountains.	Cattle.	Horses and Carriages.		Rate per 1000 gallons.
				Horses.	Carriages.	
‡	‡	‡	3*s.*	5*s.*	6*s.*	1*s.* to 6*d.*‖ 4*l.*
10*s.*‖	10*s.*	..	2*s.* 6*d.*	10*s.*	10*s.*	8*d.*
5*s.*‖	..	..	2*s.* 6*d.*	4*s.*	5*s.*	9*d.*
§	..	§	§	§	§	1*s.* 7*d.* to 6*d.*; ‖ 4*l.* to 64*l.*
¶	¶	¶	¶	¶	¶	1*s.* 9½*d.* to 10*d.*
4*s.*	10*s.*‖	20*s.*	4*s.*	5*s.*	4*s.*	6*d.*
..	..	..	3*s.*	5*s.*	5*s.* and 8*s.*	9*d.* to 6½*d.*; ‖ 20*s.*
¶	¶	¶	¶	¶	¶	From 1*s.* 3*d.*
¶	¶	¶	¶	¶	¶	From 1*s.* 3*d.*
according to size.			..	10*s.* 6*d.*	21*s.* and 10*s.* 6*d.* others.	¶
..	30*s.*	‡	2*s.* 6*d.*	Livery, &c., 5*s.*		1*s.*; ‖ 40*s.*
6*s.* 8*d.*‖	..	‡	3*s.*	5*s.* and 3*s.* others	4*s.* and 6*s.*	10*d.* to 4*d.*
¶	¶	¶	¶	¶	¶	¶
¶	¶	¶	¶	¶	¶	¶
..	..	..	..	10*s.* 6*d.*	..	10*d.*
¶	¶	¶	¶	¶	¶	8*d.* to 6*d.*
¶	¶	¶	¶	¶	¶	¶
‡	..	‡	‡	10*s.* & 6*s.* others	..	9*d.* to 6*d.*
§	10*s.* and 5*s.*	..	4*s.*	4*s.*	5*s.*	7*d.*; ‖ rental on premises.
5*s.*‖	5*s.*‖	5*s.*‖	3*s.*	6*s.*	6*s.*	9*d.* to 6*d.*
12*s.*‖ not included in rent of house.	10*s.*	..	3*s.* and 2*s.* others	5*s.* & 3*s.* 6*d.* others	3*s.* and 4*s.* 6*d.*	7*d.*
8*s.*‖ do.	..	‡	3*s.* and 2*s.* others	5*s.* and 3*s.* others	4*s.* and 6*s.*	9*d.* to 6*d.*; ‖ 9*s.*
20*s.* per acre	6*s.*	20*s.*	4*s.*	6*s.*	4*s.* and 6*s.*	9*d.*
..	10*s.*‖	..	3*s.*	5*s.*	5*s.* and 10*s.*	7*d.*
..	10*s.*‖	..	4*s.*	10*s.*	3*s.* and 5*s.*	¶
..	‡	‡	‡	‡	‡	1*s.* 6*d.*
..	5*s.*‖; max. 20*s.*	..	3*s.*	5*s.*	4*s.* and 6*s.*	¶
§	10*s.*	..	..	..	..	¶
5*s.*‖	20*s.*	20*s.*‖	3*s.*, & 1*s.* 6*d.* others.	Business 3*s.* 6*d.* Private 6*s.* and 3*s.* others. Trades 7*s.* 6*d.* for H. and C.	3*s.* 6*d.* 6*s.* and 3*s.* others.	2*s.* to 6*d.*
4*s.*‖	..	‡	‡	Livery, &c., 16*s.*		1*s.* 6*d.*; ‖ 20*s.*
¶	¶	¶	¶	¶	¶	¶
5*s.*‖	2*s.* 6*d.*	..	4*s.*	5*s.*	4*s.* and 6*s.*	1*s.*; ‖ 30*s.*
2*s.* 6*d.*‖ detached	5*s.*	..	2*s.* 6*d.*	5*s.*	5*s.* and 7*s.* 6*d.*	Varying scale from 20*s.*‖ to 1*s.* per 1000 galls. including meter rent.
3*s.* 4*d.*‖	6*s.* 8*d.*‖ garden and hose.	..	¶	¶	¶	1*s.* 3⅜*d.* to 6*d.*
¶	¶	¶	¶	¶	¶	1*s.* to 6*d.*
10*s.* 6*d.*	..	..	¶	¶	¶	6*d.*
¶	¶	¶	¶	¶	¶	¶
‖ 1*d.* per sq. yd.	..	..	3*s.*	5*s.*	5*s.* and 7*s.* 6*d.*	1*s.* to 9*d.*
§	§	.	§	§	§	¶
4*s.*‖	..	10*s.*‖	4*s.*	6*s.*	6*s.*	7*d.*; ‖ 40*s.*

¶ No Information. Shops and trading establishments are in most places charged on varying scales which cannot well be summarised.

March 4th, 1895.

WILLIAM G. PEIRCE, President, in the Chair.

NOTES ON PARLIAMENTARY PROCEDURE AS AFFECTING LIGHT RAILWAYS AND TRAMWAYS.

By W. Worby Beaumont and Stephen Sellon.

Engineering enterprise in Great Britain is at present checked by the methods and cost of Parliamentary procedure, departmental restrictions and local opposition. It is desirable that every means of removing any existing unnecessary restriction upon engineering enterprise should be carefully considered; and it is incumbent upon the engineer to show in what way Parliamentary procedure and departmental restrictions, enforced by Parliament, may be modified to public advantage.

It is a matter of common knowledge and remark that, while on the one hand the cost of transport and communication in Great Britain are in all cases high—in many cases almost prohibitory to some of the industries, and in nearly all cases greater than the cost of transport on the Continent—capital is not attracted by projects, however good, for the provision of cheaper means of transit even for districts where no facilities now exist. Capital seeks employment on moderate terms of remuneration, and cannot find it. Engineers see the necessity for improved and cheaper means of communication and transport, and are able to show how to provide it at an expenditure which may be profitably incurred. But, however good the project, capital is not attracted. Why? Chiefly because of the prohibitory burden which is placed upon almost every enterprise by the cost of Parliamentary procedure and by the restrictions which have to be enforced by the Board of Trade in conformity with its limited powers.

There are few countries in the world wherein it is more necessary to provide for cheap intercommunication between the great main roads, and for cheap transit upon them, than in Great Britain, and there are none in which the constructive work could be more cheaply carried out. There is no country in which the necessary capital is more available than it is in Great Britain; yet there is no country in the world in which so little is being done, or in which so little progress is made towards cheap industrial intercommunication by means of light railways and tramroads. The reason is that, under existing laws and Parliamentary procedure, and in consequence of the abuses connected with the latter, the cost of obtaining permission to provide the much required facilities, makes it impossible to provide them profitably. The authors propose to confine their consideration of Parliamentary procedure more particularly to those questions which affect tramways, tramroads and light railways, although in almost all branches of engineering the same procedure is necessary and the same criticism applies.

Notwithstanding the Railways Construction Facilities Act of 1864, which might be termed the Railways (Opposition) Facilities Act, and the Tramways Act, 1870, cheap legislation as affecting those branches of engineering is almost as impossible as ever, and as regards the Railways Construction Facilities Act, 1864, not one light railway has been constructed under it. Municipalisation is one of the results of this costly procedure, as it affords some limitation to certain forms of vexatious opposition and interference, but the spread of municipalisation is very far from being an unmixed good, and against it some very serious objections are urged.

All interested in the branches of engineering to which the authors have referred are familar with the various steps in the procedure under the 1870 Tramway and other Acts, and in this paper it is therefore assumed that it is unnecessary to dwell upon this part of the subject. Some of the elementary points in the proceedings have, however, in their order, to be touched upon with a view to suggestions.

Advertisements.—As one of the first steps in promotion, it is necessary to occupy large spaces in local and other papers, setting forth in the form of an advertisement an abstract of the whole of that which is completely set forth in any tramway or other Bill. Even for the smaller projects this may occupy three columns of a newspaper. Now, the whole of that which is really required in the interests of the public could be equally well set forth in a short announcement as to the name, nature and extent of the project, and the name of those from whom a copy of the Bill might be obtained at the cost of 1*s*. The unnecessary expenditure with which, under present procedure, every tramway project is burdened, is in the case of tramways further increased by the regulation which requires that after the Board of Trade has approved of the Draft Order, the same shall be printed in full as an advertisement in the local newspapers. A regulation of the Board further adds to the expense by encouraging the ingenuity of some newspaper publishers in finding reasons which prevent their publishing, at the required date, the Bill or Order after Board of Trade approval—reasons which are said to be absolutely unsurmountable, although always evaded by the payment of extra special rates. This is the result of the rule requiring that the second announcement shall appear in subsequent issues of the same papers as the first. These announcements have, really, little if any value; no one reads them for amusement, and those who for business reasons have to read such dry matter resort to a copy of the Bill or Order. The cost of this very extensive advertising has often imposed very heavy strains on the resources of a small tramway company, for it must be noted that these expenses have to be met in the preliminary stages of the project, when the money available is necessarily a speculative advance which subsequently has to be paid for by the public at an enormous premium if the Bill goes through. Men will not provide the funds for bringing forward a project, which after all may be rejected, except under the promise of such large gains that the possible profit to them justifies the risk of total loss of the sum advanced. These large sums afterwards, when the Bill goes through and the public subscribes the capital, form a first charge and not infrequently impose a burden which swallows up all and more than all the profits from running the concern. By reducing these preliminary expenses to a nominal sum, all this, as will be seen, might be avoided.

Plans and Sections.—Here, again, great and unnecessary expenditure is involved in the adherence to old rules and regulations, which ought long ago to have been deemed obsolete, as the reasons on which they are founded admittedly are. In past times, when no Ordnance maps were available, the usually inferior, although specially made, lithographic plans were necessary, but to-day they would be economically and advantageously replaced by Ordnance maps with the line of the proposed tramway drawn upon them. Sections are not necessary, although according to rules they are required, for it is useless to give a section when nine words in the Bill inform the public that "the tramway level is that of the roadway traversed," and even in the case of railways, where new levels are followed, it should be sufficient to make it incumbent upon the promoters to supply at a nominal charge, tracings of so much of the section as actually concerns any applicant.

Deposit.—In connection with light railways and tramroads or tramways, the deposit now required and the payment of ½ per cent. of the intended capital on the passing of the Act should either be materially reduced or abolished altogether. If these lines are to be made for the benefit of industries and populations now suffering from the want of sufficient means of transit, it is desirable that relief in this respect should be complete. Most of the lines would be constructed along or beside roads, little land required, and (unlike a main line of railway which would render much property idle if not proceeded with after the Act), no losses would be incurred by any owners. There would, however, be no objection to a deposit after obtaining the Act and before commencing construction.

Committees.—The present system of legislation, which requires the Promoters of Private Bills to appear before separate Committees of each House to prove the preamble of their Bill, is most prejudicial, and can be of no use, except to the pockets of those whose duty it is to steer these Bills through the House. It entails a lamentable waste of time and of money that should be available for construction, and necessitates the duplication of the same identical evidence before each Committee. An easy way of avoiding this difficulty, if the procedure is necessary at all, would be to appoint Joint Committees to hear the evidence of the opposition to all Bills. This would not involve any necessity for a joint decision, as those representing each House might be free to give their own independent decision.

Private Agreements.—In many cases it is necessary in Private Bill legislation, especially where municipal interests may be involved, to require the promoter of any particular scheme to obtain consent from the Local Authority or Local Authorities within whose jurisdiction the proposed works would be, before he can be heard on the merits of the Bill. The objection to this is that it unnecessarily and sometimes enormously increases the cost of passing Standing Orders. The law as it stands gives a fictitious importance to this consent, or an importance at an improper and harmful stage in the history of any Bill. In view of public advantage it is, moreover, a disastrous requirement, as it sometimes stops a useful scheme almost at the outset. Local Authorities and other opposing interests are enabled to impose conditions almost prohibitory, but these conditions, as well as blackmail, are made the subject of agreements which the Committees never see. Moreover, these conditions may be to the pecuniary advantage of but one or two of the members of a Local Authority, but if the promoter refuses to accept them, the influence of the one or two members may be quite strong enough to obtain the adverse vote of that Local Authority. That these things are done is only more discreditable to the Local Authorities, than it is to the legislation that makes it possible. By assenting to these conditions or payment of blackmail, promoters have obtained Acts by proving to the Committee that the Acts would be to the public advantage. But these Acts would probably not have been obtained if the Committee had known of the existence of these agreements, for they have in some cases doomed the projects to commercial failure from the first. If a project is likely to be to the public advantage, there should be no influencing conditions which may not be made public. The authors, therefore, hold that all agreements having any relation to Promotion, Construction or Working should be supplied to the Committee, and the Committee should decide whether or not such agreements should be in the Bill or modified, or struck out, whichever they deem best.

Estimates.—During the progress of both opposed and unopposed Bills, it is desirable that Parliament should consider closely the relationship between the proposed capitalisation of the Company, and the reasonable cost of the proposed work. It is usual to restrict the amount of Debenture in Tramways to a quarter of the Paid-up Capital, but this is very little, if any, protection to the investor, as it is only necessary to make the Share Capital large enough to obtain Debenture Capital far beyond the value of the property. The necessity for the consideration of this matter by the Committee is shown by an examination of the capital cost of tramways in the United Kingdom, without considering the Debentures. The formation of a new Company under the Limited Liability Act of 1862, for the purpose of taking over the property and rights of a restricted statutory company, and with unrestricted borrowing powers, is a common occurrence. This is a form of procedure which enables promoters to obtain capital out of all proportion to the sum which can be profitably employed.

The tramway returns show that for every mile of tramway constructed in this country 15,000*l*. has been spent, which is about three times as much as a single mile of any ordinary tramway should cost to construct; that is to say, expenses other than those of construction and engineering, upon which a dividend could be earned, have gone in ways which have purchased no tangible asset. This money, nevertheless, has to be reckoned when the price of fares and rates have to be arranged. At the present moment no less than 1,750,000*l*. spent on tramways in Great Britain pays no dividend at all, and without doubt the chief cause of this is the disproportion between capital and true cost. The Acts for these tramways were obtained because "the construction of the same would be to the public advantage." The best advantage to the public in this case would be cheap fares, but such a very high capitalisation made it impossible to realise this from the first. The Committee should therefore consider the relation between capital and reasonable cost, especially in connection with unopposed Bills.

Opposition.—It has been a common thing in the past for a Promoter to be placed in such a position that he must either accept the clauses demanded by a wealthy and powerful opposition, and so do away entirely with the value of his Bill, or abandon it. Even should he decide to fight it, his opponents have the power to extend the period of opposition for such a long time in both Houses that they can impose a burden in capital expenditure on the undertaking, which is so heavy that it cannot be borne without being seriously prejudicial to the advantages obtained from the Act. Opposition of this kind, even when the Committee decide that the Bill would afford things "to the public advantage," cripples the undertaking and only gives the public something to which they may subscribe and upon which they may lose their money. The prayer is granted, but the grant is worse than useless as far as any public advantage is concerned. It is therefore very important that, if the present system is continued, the powers of the Committee, to make the losing opposition pay the whole cost of the inquiry, should be much more strongly enforced, especially if there should be any proof during the inquiry that the opposition is frivolous or due to mainly personal interest.

The enormous cost of obtaining the powers to construct the Manchester Ship Canal is a good example in connection with this argument. This Bill would never have become an Act had not the promoters been able to show the Committee that the then existing monopoly, enjoyed by the railway companies, enabled them to charge a rate which was detrimental to the trade of Manchester and district, especially as this scheme was almost without precedent. The opposition, as subsequent events have proved, was clearly for the purpose of maintaining a harmful monopoly, and this Bill would never have been promoted except as a consequence of the existence of this combination, or, being promoted, would have cost a comparatively small sum to comply with Standing Orders. The Committee in giving their decision might therefore very properly have ordered the various railway companies to pay the cost of the inquiry.

Delay.—The length of time at present absorbed in obtaining powers by means of Private Bills or Provisional Orders might not perhaps be advantageously shortened to any considerable extent for the public works for which they are mostly required. There is, however, something very unreasonable in the system which makes it necessary to occupy half a year to get Parliamentary permission to carry out a project to which all the local authorities concerned have given consent. It is also absurd that the same length of time and the same machinery should be necessary to get permission to make a 10,000*l.* tramway as to make a 100,000*l.* railway.

Board of Trade Powers.—For the foregoing reasons it is clearly necessary that powers should be obtainable for the minor projects by some shorter and more rapid means of legislation. The authors therefore suggest that the Board of Trade should be given the power to hold local inquiries and grant permission to carry out schemes, just as the Local Government now conduct inquiries, and without the delay necessarily entailed for a confirmation Act. This would very materially assist enterprise on tramroads and other works, and would make it possible for a small tramroad company to proceed as cheaply as a private owner can with a line on his own property.

It is, moreover, desirable that Private Bill procedure should be so amended that not only shall less of the time of those who may be called on to give evidence be wasted, but it should not be necessary to bring witnesses to London from Ireland and Scotland for the purpose.

As an example of the necessity for more freedom in the exercise of discretion with regard to mechanical and minor matters affecting tramroads, it may be mentioned that whilst every tramway Act permitting the use of mechanical traction requires all steam locomotives to be fitted with automatic speed governors and brakes, a requirement which the Board of Trade officers are bound therefore to enforce, no such requirement is demanded by them with regard to electrical tramcars. They do not feel bound to enforce it because electric locomotives are not steam locomotives. Part of the South Staffordshire tramways is worked by seventeen electric motor cars, weighing six tons each, where formerly it was worked by steam locomotives. On this piece of line no such automatic governors and connected brakes have ever been found necessary, neither have they at Leeds or Blackpool.

Clauses such as these inserted in Tramway Acts hamper the engineer in the proper working of a line, and the Board of Trade official becomes a mere clerk of works following a specification, whereas he should be free to insist on or to relax provisions with regard to mechanical details according to circumstances and to the requirements of the case as affected by progress in construction, and by the demands of a district or by the kind of traffic.

The case of the Longton extension of the North Staffordshire Tramways is another of many examples showing the necessity for change with regard to the Board of Trade and the clauses in various Acts. The Provisional Order for this line was obtained after inspection and report by a Board of Trade inspector, but after the line was completed at a cost of about 25,000*l.* the Board of Trade refused to pass it, because one street through which it passed was below statute width, and with the result that although the Longton Town Council has done its best to get the Board of Trade to relax its requirements, yet that 25,000*l.* of capital has been completely lost and the inhabitants of Longton complain to this day of the want of tramway facilities.

It may not be necessary, but it will perhaps be as well to state that the authors have no intention of suggesting that the private interests of the promoter or promoters should ever be allowed to weigh in the least as against the similar interests of individuals. They think, however, it is clear that, inasmuch as no public work of the kind here referred to should be permitted unless of public advantage, facilities should be granted for the promoters to show public advantage and merit before the opposition of the individual steps in.

It must further be pointed out that inasmuch as the promoter of a tramroad could not proceed without the consent of the majority of the inhabitants, it would be to the public advantage that the merits of a scheme should be considered before opposition to it is taken. In this way much of the vexatious opposition which at present adds greatly to the cost of a project, would be avoided, and some of the agreements extracted from promoters before Standing Orders, and kept secret afterwards, would never have to be entered into. The private interests of individuals must be carefully guarded as now, but it is most desirable, when a scheme is declared to be a necessity and of public interest, that the merits of that scheme should be first examined, and if endorsed, then the objections should be heard with the object of modification, so that objectors may be protected and satisfied. If the wish of the public, as shown by its consent, is that a scheme should be carried, its rejection should not, as now, be based on the objections of a few individuals unless it can be shown that injustice would otherwise result. The authors are not suggesting any new form of legislation, this procedure being the universal order of procedure in France, and one which is also largely adopted in Belgium, in connection with its numerous secondary railways and tramroads.

The result of this policy abroad is, for instance, in Belgium with a population of about six millions, that in addition to their extensive system of railways (which is greater in mileage per head of population than that of Great Britain), they have at the present moment 730 miles of light railways working, 40 miles in construction and 900 miles projected to be constructed, representing a capital of 4,888,000*l.* or nearly 1*l.* per head. It may be suggested, therefore, that under reasonable legislation there is, on the same estimate, employment for about 35,000,000*l.* of capital in Great Britain on light railway and tramroad works. In 1893 the mean dividend paid on all the Belgium lines was equal to 2·8 per cent.

Since the foregoing paper was prepared, the Board of Trade Committee on Light Railways has been proposed—has met and has agreed to its report. It would, however, be more correct to say that most of the members of the Committee agreed to sign a report with which many of them disagreed, and no less than nine members out of the twenty-five forming the Committee drew up and signed separate dissentient reports or appendices.

The questions referred by the Board of Trade to the Committee were:—

1. How far the usual requirements of the Board of Trade as to constructing and working new railways may fairly be relaxed, especially in the case of lines built through sparsely populated and agricultural districts.

2. Whether additional legal facilities for obtaining powers to construct tramroads and light railways are necessary or desirable.

After sitting many days, the Committee found that the usual requirements of the Board of Trade might with advantage be relaxed with regard to light railways and tramways; and that legal facilities for obtaining powers for constructing such lines were required. The Committee did not, however, sufficiently specify the directions in which either the relaxations in the Board of Trade rules and regulations should be made, nor the direction or scope of the proposed legal facilities either with regard to promotion, land, fees, capital, or procedure.

The several appendices to the main report will generally be considered as of more value than the report itself. The authors here reproduce that which, when afterwards abridged, was signed by seven members of the Committee, including Mr. Sellon. This minority report presents many points worthy of careful discussion, and was as follows:—

"We regret we are unable to sign the report, and beg to give our views upon the questions submitted to the Conference.

"(1) The Committee considered closely the present law as well as the Board of Trade and local regulations concerning tramways of the first magnitude, such evidence having occupied the attention of your Committee for two sittings, and has been the subject of constant reference throughout their deliberations.

"(2) To relieve the congested districts; to afford communication between urban and suburban districts, and also to provide facilities for the transit of passengers and goods from and to the great cities, large extensions of the existing tramway systems would be most advantageous and naturally would not necessitate the purchase of valuable land, either for terminal stations, or for carrying the lines through towns, and would, in addition, get rid of terminal charges, and the construction of the most costly works of a railway, viz., tunnels, cuttings, embankments, viaducts or bridges, stations, and expensive signalling and interlocking apparatus. In many cases such lines could be made at the sides of the roads, or on the waste land at the sides, thus avoiding any extensive interference with the public highways.

"(3) It is to be regretted that the railway companies do not appear to have seen their way to have made any serious attempt to construct light railways as feeder lines. Had they so desired, special powers might have been obtained for the purpose without regard to the Light Railways Facilities Act, 1864, especially after the adoption by the Standing Orders Committee of the word "tramroad," a distinction made to enable light railways to be constructed under the Tramways Act with no statutory regulations as regards speed or working unless they are laid on the public highways, in which case modified regulations under the Tramways Act apply. Parliamentary sanction has been given for the construction of several miles of this class of line, and they would have been made if the projectors had been possessed of the same advantages which railway companies have when promoting extensions of their own systems.

"It is not generally understood that tramroads are entitled to the benefits of the Railway and Canal Traffic Acts, and can therefore insist on having working agreements with the neighbouring railways as if the tramroads were railways.

"We consider that the lack of progress in the construction of tramroads or light railways as feeders has been due to the want of more generous treatment by railway companies, and as an example we refer to the Southwold case. It appears to us that such treatment would not have been detrimental to the interests of the railway companies.

"(4) We think that the statement in the report as to the lack of progress, and the impediments to the construction and restrictions on working, does not sufficiently represent the actual facts, as it is well known that obstacles to the construction of tramroads and tramways have been unnecessarily interposed by the local authorities and the Board of Trade, notwithstanding that either of these bodies have the power to modify or relax many of their requirements.

" We recommend that the Board of Trade should have full power to modify or dispense with any of the existing restrictions on the construction and working of tramways.

" The absence of progress in this country is best illustrated by showing the mileage of secondary railways alone, not including tramways open for traffic in the following countries, from official information given to the Committee:—

		Miles.
France	1893	2250
Hungary	1892	2300
Germany	1892	1620
Italy	1890	1250
Belgium	1893	770
Netherlands	1894	160

" (5) With regard to the expenses of promotion, we recommend that where County Councils are themselves promoters of light railways, tramroads, or tramways, no deposit should be necessary, and that where independent promoters seek to obtain similar powers, no deposit should be payable until the lines have been authorised and the work of construction about to be commenced, in which case a deposit should be made to the local authority; such deposit being returnable with interest *pro rata*, on the completion of each section of line as may be agreed.

" With a view to reducing the cost of promotion, we recommend that instead of the present mode of procedure it is desirable that Parliament should authorise the Board of Trade to sanction the construction of light railways, tramroads, or tramways, which are approved by the County Council concerned, and in cases where several County Councils are interested, the Board of Trade, after holding a local inquiry, should have power to overrule the objections of the minority.

" (6) As under the present Standing Orders affecting tramroads and tramways, one frontager has prevented Bills being considered on their merits, we recommend in all cases of opposition by frontagers, that claims both as to opposition and compensation should not prevent a Bill or Order being considered on its merits, and if the proposed line is shown to be of public utility, the opposition of such frontager or frontagers should be overruled.

" (7) The Committee considered the question of acquiring land by compulsory powers, and we recommend that the principle adopted by the Local Government Act of 1894, in regard to the compulsory acquisition of lands for certain purposes, should be extended so as to enable local authorities to purchase lands necessary for proposed lines.

" We consider that it is contrary to the public interest to grant, without the closest inquiry, any powers for the compulsory acquisition of land by any railway, tramroad, or tramway company, which is desirous of obtaining powers for the conveyance of goods, and not of passengers.

" (8) The Committee have had abundant evidence to convince them that, except in isolated cases, it would be impossible, under existing conditions, to obtain from the pulic the financial support necessary to enable light railways, tramroads, or tramways to be economically constructed, and we feel, therefore, that having regard to the terms of the reference and to the speech of the President of the Board of Trade at the recent Conference, it is our duty to state our opinion that, following the precedents in Belgium and other countries, the County Councils and other local authorities should be empowered to subscribe or guarantee capital or interest on capital for this purpose."

It will be seen that several of these proposals have already been discussed in the former part of this paper. There are many others open to discussion, but as two papers on the present subject have been read elsewhere since this one was prepared, most of the matters in question will have been presented for consideration.

DISCUSSION.

The President said that he had much pleasure in moving a vote of thanks to Mr. Beaumont and Mr. Sellon for the admirable paper to which the meeting had listened. The subject was one of very great importance just now with regard to the construction of light tramways to act as feeders to railways by the conveyance of agricultural produce to railway centres.

The vote of thanks was heartily accorded by the meeting.

Major-General Webber, C.B., said that the paper was one of extreme practical utility and importance. He thought that the meeting would endorse the statement with which the paper opened, namely, that " engineering enterprise was checked by the methods and cost of Parliamentary procedure, Departmental restrictions and local opposition," and that statement would be of the greatest importance if it went out to the world with the approbation of such a meeting as was then assembled.

He thought that the reason that the costly procedure had flourished, and the tax on railways had been so great as to restrict the promotion of new works, was that the voice of the engineer had not been heard often enough in connection with this subject. A case which had come under his own notice afforded a signal example of the mischief which a Parliamentary Committee might do. A Bill for a railway intended for light traffic, and promoted for the purpose of joining two important points, had come before three Committees of the House of Commons. On the third occasion, when the total cost of procedure had amounted to nearly 10,000*l*., the counsel for the opponents remarked to him (General Webber) "You are all right to get your Bill: it will only be a question of clauses." The room was cleared in the usual way for the Committee to deliberate, and the parties had scarcely time to get into the corridor before they were called back and told that the Bill was thrown out upon the preamble. There could not be a more striking example of the inconsiderate way in which a Committee of the House of Commons dealt with subjects of that kind. Everything which Mr. Beaumont had said with regard to the necessity of having schemes thoroughly weighed upon their merits by people who understood them before the legal questions came forward, he (General Webber) could fully endorse from his own experience.

With regard to light railways, he believed that the assistance which they would give to agricultural industry required to be brought before the agricultural mind. There was no doubt that at the present moment there was thoughtless opposition to them in some purely agricultural districts. At present agriculturists looked upon light railways in very much the same way as they looked upon main lines of railway which ran along by public roads, and feared that they would frighten their horses. He believed that farmers would raise the question of frightening horses and cattle even if they could show that light railways would be a pecuniary advantage to them. If the decision was left to parish councils or even to district councils, the opposition to the construction of a light line along the many miles of waste by the side of the country roads might still on that account be very considerable. The subject of light railways should be ventilated thoroughly, and the farmer should be shown that his produce could be conveyed by them more economically than by his existing means of transport. The gauge of such railways must be governed by that of the portable branches, which, to make the system really practical, should be capable of being laid up to the homesteads and into the fields. He believed that landowners were convinced that farmers ought to encourage in every way the use of such means of transport. The extension of light railways in Denmark, Belgium, Holland and the north of France had been a great advantage to the agriculturists of those districts. He had been informed from the best sources that the light lines which of late years had been constructed in the countries which he had just mentioned, made their profit largely from the transport of goods which eventually reached the London market, and that if it were not for the London market, those lines would not have come into existence to the extent they had.

Dr. D. S. Du Riche Preller said that, having had a very large experience of light railways and tramroads in various parts of the Continent, he cordially agreed with the arguments which the authors had put forward. What was wanted was a clean sweep of the existing regulations of the Board of Trade and of Parliamentary procedure as at present constituted—in fact, an entirely new departure. Parliamentary procedure was absolutely unnecessary for tramroads. He would vest the power of authorising such lines in the central authority without having to go to Parliament, and to be exposed to frivolous opposition. Within the last few weeks concessions had been granted in Switzerland for tramlines for which he had submitted the plans, and in which existing roads were to be utilised. The procedure in that country was simplicity itself. The line was set out on the 3-inch Ordnance map, and that was accompanied by a longitudinal section to the same scale, by standard cross sections, designs of permanent way and rolling stock, by a general report of the line, and by an estimate of cost of construction and working. The plans were sent to the canton authorities, which were similar to the county councils in this country, and also to the authorities of the central government. The authorisation of a tramline depended in the first instance upon the owner of the road. In the case to which he was referring it was the cantonal government. That authority fixed the gauge, the standard section, the width of road to be left for the ordinary traffic and so forth ; and the central authority granted the complementary concession which stipulated for the safety of the traffic, fixed the train service, the speed, and rates and fares. The company had to be formed within two years, and one-tenth of the share capital had to be paid up. The company could then issue debentures for half the total capital and commence work. That was what should be done in the United Kingdom. He had also had considerable experience of lines in Italy. The procedure in that country was very similar to that in Switzerland. With regard to the rates to be charged on light railways, he considered that the Parliamentary fare, namely, a penny a mile, was too much in sparsely populated agricultural districts, and would not attract traffic. In Belgium, France and on the Continent generally, the third-class fare on all railways was 5 centimes per kilometre, equal to three-farthings a mile. The English Parliamentary fare was equal to second-class fare on the Continent generally. The objection raised by farmers against tramroads on the score of the horses being frightened was met with everywhere; but experience showed that horses soon got accustomed to the short trains hauled by mechanical traction, and in many cases farmers sold their horses after a time and used the tramroad.

He believed Mr. Sellon would agree with him in the opinion that there was ample room for using electric traction on light railways and tramways in this country. It had been said that electric traction would not pay on a line which cost 6000*l.* a mile and ran only two trains a day each way; but he wished to point out that no line, whatever it might cost and whatever kind of tractive power was used, would pay if it ran only two trains a day each way. On a line eight or ten miles in length, electrical traction would give greater facilities than any other system of mechanical traction, because, although the trains were shorter, they could be run much more frequently. As compared with steam there was a better utilisation of power in the case of electricity, and consequently a material reduction of expenses. He could quote cases within his experience in which the saving in traction and power expenses was quite 50 per cent. Electric motor cars were absolutely noiseless and smokeless, and horses would not shy at them. He was glad that the authors advocated tramroads rather than light railways. The cost of procedure in connection with the promotion of a railway and of the acquisition of land was so great that many railway schemes were, and would be, still-born. The difficulties occasioned by the steep gradients which were met with on many of the ordinary roads could be overcome better by electricity than by steam. A gradient of 1 in 10 could be ascended with perfect ease by electrical traction. The objections founded upon insufficient width, and upon sharpness of the curves on ordinary roads could be removed by widening the roads and altering the curves. The expense of doing so would be much less than the cost of the acquisition of land for an entirely new line.

Mr. A. T. WALMISLEY said he joined with the previous speakers in commendation of the paper. The subject was one of the questions of the day, and it had been treated in a very comprehensive manner. The great point to be borne in mind in relation to light railways was that they should be made useful to the farmers in conveying their produce to the market towns. It was desirable to avoid unloading and reloading in transit, and in order to do that there should be no change of gauge. The object of light railways was to cheapen the cost of transit, and therefore the light rolling stock of the light railways should be constructed so that it would travel over the main lines, though of course the heavy rolling stock of the main lines would not be able to travel over the light railways. He would like to see a prescribed limit for the overhang of tramway carriages beyond the gauge. At Leeds, where they had steam tramways, the gauge was 4 feet 9¼ inches, and the width of tramcars was 6 feet 9 inches. On the Greenwich and Plumstead line the gauge was 3 feet 4½ inches, and the width of the carriages 5 feet 9 inches. Upon the Metropolitan line of tramcars (Greenwich route) the gauge was about 4 feet 7½ inches, and the tramcars measured 6 feet 6 inches over all. Thus while the gauge of one tramway was 15 inches narrower than that of the other tramway, and the latter approached the ordinary 4 feet 8½ inches railway gauge, the carriages were only nine inches narrower. What was the use of having the gauge of the metals narrower if only nine inches was saved in the width of the carriages? He agreed with the proposal to lay out the plans of light railways on the Ordnance map. Such a course would have the advantage of showing the district through which the new line was to run. The surrounding neighbourhood beyond the limits of deviation was generally left out as much as possible upon Parliamentary plans for reasons best known to engineers. He did not, however, agree with the view of the authors, that sections were unnecessary. The object of a section was to indicate the gradients, and it was important that this should be done, and considered when determining the type of traction.

Mr. T. W. Staplee Firth said that the very interesting paper which had been read seemed to strike at the very root of a great many evils. If those evils were removed, an opening would be made for the employment of a large amount of surplus capital, with which the public at the present time did not know what to do. He knew of an exceedingly good agricultural district, within a hundred miles of London, but which was seven miles from any railway station. The clumsy and expensive procedure which had to be resorted to in order to get a Bill through Parliament, crippled many undertakings. He believed the inhabitants of agricultural districts did not realise the inestimable benefits which would be brought about by the establishment of light railway facilities in their midst.

Mr. E. Benedict said that the paper was an eminently practical one, and if it was well studied by the authorities it would show them a way out of some of their present difficulties. There was no doubt that another great advantage to trade would be to effect an immediate saving in the cost of collecting and distributing produce. He was afraid that railway rates could not be cut down while the dividends were so small and the Board of Trade kept increasing the number of people that had to be employed on railways. It was very absurd that English people still stuck to the antiquated mode of getting their produce from the fields and villages to the railway stations. It had recently been stated that the inhabitants of Sevenoaks combined together and obtained their goods from London through the carriers, who brought them down and distributed them at a cost which was exactly half that charged by the railway companies. He thought that was the line of action which should be taken in the carrying of goods from one place to another, thereby reducing the expense of collection and distribution. Supposing, for instance, that the vehicles carrying the goods were run on plates of iron instead of being dragged along a macadamised road, the cost of traction would be at once reduced. Tramways would still further cheapen the cost of transit, and should enable produce to be put on the railway without transfer from vehicle to vehicle being necessary. At present, the tramroads were made with a groove too narrow for the flanges of railway stock. A different construction would have to be adopted if transshipment of the goods was to be avoided. In every case, whatever system was best fitted to the particular circumstances should be adopted. No rule could be laid down. No body of persons would be in a better position to carry out the necessary work than the railway companies in the neighbourhood. It seemed to him that they must not depend upon any system which would bring an additional burden upon the rates. The work must be done by outsiders, with the consent of the local authorities. It would, therefore, appear that the only way of achieving what was desired, was to establish a carrier company, working in conjunction with the present carriers in the district, whether they were railway companies or otherwise.

One great object to be kept in view in this movement was to give work to the unemployed, whether they were engineers or labourers; now for one mile wanted in England there were certainly ten wanted in India. One speaker had called attention to a case in which the produce had to be carried seven miles to a railway station. He (Mr. Benedict) had before him a map of India, which showed that it would be a very extraordinary thing in that country if produce had to be carried only seven miles in order to be put upon a railway. In India, the feeders of a railway system, whatever they were, would not be opposed by Government, whereas it was now very difficult to find any railway that would not be opposed by Government in that country. The Government had an increasing interest in the Indian railways, and it was very difficult to lay out a line which would not, in some way, compete with the existing lines. Feeders, however, would not so compete, and, therefore, there was no doubt that the Indian Government would encourage them. In many respects England might take a lesson from India, although the latter was considered to be very far behind. The Indian Midland Railway Company had for years past had out-agencies from ten to fifty miles from their stations, where goods were collected and taken over by the railway company. In fact, the company's carters would take produce from a field and be responsible for it as soon as it was loaded up on the carts. The difficulty had been the want of good roads, and of bridges on those that were otherwise fairly good. Those difficulties would not occur in England.

Mr. J. C. **Fell** said that the authors had been so much complimented by the previous speakers, that perhaps they would not object to a little friendly criticism. It would appear that the object of the paper was to suggest that engineers were handicapped, and that the country failed to obtain the benefit of a large amount of railway work by reason of preliminary expenses incurred by the opposition of Bills in their passage through Parliament. There were, however, two sides to that question. A proposed line very often came in conflict with vested interests, which had already laid out capital in the district. Those interests must be allowed to have a voice before any rival scheme was forced upon them, or capital would be discouraged. Of course that consideration might be met by the argument that the necessary opposition might be allowed to existing interests, and that nevertheless the procedure might be made much cheaper. Again, there arose a question as to what body a scheme should be referred for sanction, if it did not undergo the present Parliamentary procedure. He rather fancied that the authors of the paper would suggest local bodies, but, as a previous speaker had remarked, the greatest opposition of all might be found among such bodies. He was not at all sure that experience did not show that the more local a body was, the more difficult it was to move it away from preconceived notions. The very people for whose benefit a new system of light lines, to act as feeders, was being promoted, would be the very people with whom the greatest difficulty would be experienced in convincing them of the advantage of the scheme. He did not know that that difficulty could be dealt with by engineers. As engineers, they were perhaps doing their part by ventilating the matter among themselves. No doubt it would be a very great advantage if agriculturists generally could be made to see that they were behind the times. The prejudices of English people were deeply rooted; there was an idea that what had been, ought to be continued. The development of light railways for agricultural produce was only meeting with the same opposition that railways met with in former days. He was unable to see that even the expenditure of many thousand pounds in Parliamentary expenses would prevent a railway from paying in the long run. All Parliamentary charges were written off capital account. What had to be considered was whether, with the heavy wages which had to be paid at the present time, and the other accessory current expenses, a railway or tramway could be made to yield any net revenue at all. If it could not, it did not much matter what the capital was. If there was any net revenue after deducting working expenses the probability was that the railway would pay something, even if the capital was inflated by a certain amount of Parliamentary expenses.

Mr. PERRY F. NURSEY said that in most statements and discussions respecting the present subject, light railways were put forward as an important means of assisting the distressed British farmer. In the recent speech from the Throne, the serious depression in agriculture was referred to, and the construction of light railways was suggested as a means of alleviating the distress. But the proposition of General Webber and others implied the support of the distressed agriculturist himself in constructing the means of his own salvation, whereas the average British farmer at the present time could hardly find the money to carry out some of the most necessary farming operations. Therefore he did not think that it was possible to look to the British agriculturist for any help in the construction of light railways. Neither could they look to local bodies for that assistance, inasmuch as some of the expense must necessarily fall upon the farmers of the district. It therefore became a matter purely of outside capital, and there naturally followed the question, "Will it pay?" In the present depressed state of agriculture, he did not think it would pay. Of course it might be that the position of agriculturists would be improved if they had a ready means of moving their produce from the point of production to the point of sale, but on the whole he thought the agricultural cry was about the last that should be raised to rally capital. There were, of course, conditions under which light railways would prove eminently satisfactory if they could be constructed at a low cost, but those conditions were entirely independent of those of the relief of agricultural distress.

The other question which had been raised by General Webber, namely, the frightening of horses, was a very old bogey, which had been practically laid time after time as soon as it cropped up. When railway extensions into the metropolis were first mooted, the cry was raised. A very direct and practical answer was given by the railway from Fenchurch Street to the Millwall Docks. The line, over which he frequently travelled, ran parallel to the public road at Canning Town for a very long distance, but the street traffic went on as it did before the railway was made, and as far as his observation went the horses took no notice whatever of the passing trains. The experience was similar with regard to steam-worked tramways which traversed the public roads in some provincial towns.

It had been suggested by Mr. Walmisley that the ordinary 4 foot 8½ inch gauge should be adopted for light railways in order that the rolling stock should be capable of running on the main lines, and that the stock should be constructed of a very light character. But it occurred to him (Mr. Nursey) that directly any of such light rolling stock got upon the main lines and was worked in with the heavier rolling stock of the railways it would not be very long before the light waggons came to grief. He therefore thought it would be undesirable to construct the light lines with a view to running the rolling stock on the main railways.

Mr. E. R. Dolby said he disagreed absolutely with the remark made by Mr. Walmisley, that it would be preferable to construct light railways of the ordinary gauge. Any one who had visited the works of Messrs. Decauville, in France, or had seen the work that had been done by Messrs. Fowler, of Leeds, or Messrs. Dick Kerr & Co., of Kilmarnock, must know that such lines as those firms constructed on a very narrow gauge could be made cheaply. He agreed with the authors of the paper that light railways should be carried along the highways, but it would be impossible to form passing places in such positions for vehicles of the ordinary railway gauge unless extra land was acquired. A great deal had been said about breaking bulk, but they must break bulk somewhere. If the light lines were made with a gauge of 2 feet and were furnished with portable portions about 12 feet long, the vehicles could be taken by the farm labourers into the fields to collect the produce which had been taken from the ground, and after being filled could be run back through the farmyard and placed upon the lines. Those small vehicles and portable lines could be let out on hire to the farmers, or the farmers could purchase them.

Mr. E. Garcke said that the main fact which they had to consider in discussing light railways was that Continental experience pointed to a very low cost of construction. He believed that the average cost of construction in some Continental countries was between 3000*l.* and 4000*l.* per mile, and that the average dividend was from 2 to 3½ per cent. It would not be sufficient in any legislation which might take place to deal simply with the question of Parliamentary procedure or with the relaxation of the Board of Trade regulations and other relatively small matters of that kind. If engineers went away with the conclusion that the whole question would be solved by the removal of the difficulties which the authors had pointed out, they would be disappointed. He hoped that the various discussions which were taking place with regard to light railways would be prolonged until after the Bill which the Board of Trade was promoting was brought forward, and he trusted that they would then discuss the Bill for the purpose of seeing what amendments they could suggest with a view to the measure being made as useful as possible. The authors had dwelt upon the desirability of the Parliamentary procedure and the Board of Trade regulations being materially modified. There were some other important questions in connection with the promotion of light railways. They were the acquisition of land and the obtaining of capital. Another large question for consideration was, what should be the relations between the light railways and the main trunk lines? Some of those questions might not be engineering questions, but they were so closely connected with the successful development of light railways, that they must not be overlooked. The paper contained the important statement that on an average the capital expenditure upon existing tramways in the United Kingdom had been 15,000*l.* a mile, while the cost of the construction was estimated to be only about 5000*l.* a mile. That left 10,000*l.* to be accounted for, and it was not entirely accounted for by the difficulties which the authors had pointed out in their paper. It was evident that a great deal would have to be done before the cost could be brought down to something like 4000*l.* a mile, and it seemed to him that unless they could succeed in bringing it down to that sum, the development of light railways in sparsely populated districts in this country would take place only on a small scale. The modification of Parliamentary procedure and the relaxation of the Board of Trade regulations would account for only a very small portion of the excessive cost.

He thought that the acquisition of land and the renewing of the capital had been too lightly dealt with in the discussions which had taken place. It had been very truly said that there was capital lying idle, but the reason of that was that the public had not sufficient confidence in the investments which were offered to them. Capitalists would be satisfied with a small rate of interest if they could have good security, and unless light lines could be constructed at a low cost, they would not be able to offer proper security to the investing public. That fact was shown by the statistics of the Continental lines. The amount subscribed to those lines by private individuals was exceedingly small, amounting only to about 10 per cent. The rest was provided by the Governments and the municipalities. He thought they might safely rely upon the light lines yielding a satisfactory return if the cost of construction was low, and, therefore, there would be no great risk incurred either by the Government or by local authorities if they guaranteed a minimum rate of interest to the investors.

Dr. PRELLER referred to the statement made by the last speaker with regard to the cost of Continental lines. He was aware that there had been a few light lines constructed in Sweden and also in Italy at 2000*l.* per mile, but they were so inferior in every way that he should be sorry to see such lines constructed in this country. He believed that, including preliminary expenses and all other charges, it would require 6000*l.* a mile to construct and adequately equip a serviceable line, having regard to the higher cost of labour in this country. That would correspond to from 4000*l.* to 5000*l.* per mile abroad.

General WEBBER observed that the rolling stock was not included in the 2000*l.*

Dr. PRELLER said that that would make a difference of only 1000*l.* With regard to the return obtained on the capital he could state from his own knowledge that many lines which had cost from 4000*l.* to 5000*l.* a mile paid a dividend of 3 or 4 per cent. The difficulty connected with the break of gauge between light narrow-gauge lines and normal-gauge main lines was overcome in many cases within his knowledge by loose four-wheeled cradle trucks being run on the narrow-gauge lines, and the trucks of the normal gauge being carried upon them, the load, of say 16 tons, being distributed over eight wheels. That system had answered very well indeed, and prevented any difficulty being occasioned by the change from narrow to broad gauge.

Mr. S. H. TERRY said he did not agree with Mr. Garcke as to the authors having dealt with only one small portion of the subject. He admitted that the question of the break of gauge was a very serious one, as Mr. Walmisley had said, but he did not agree with the view that the light railways must have a 4 foot 8½ inch gauge so that the carriages or waggons might be run on the main lines. No traffic manager or carriage builder would view with favour the putting of the two classes of railway stock in the same train. In case of accident the light carriages would fare rather badly. There would be no very great advantage in endeavouring to construct the vehicles of the light line so that they could run on the main lines. Break of gauge must take place somewhere, and he thought that it could be most conveniently dealt with at the country stations, where the two classes of lines met. There was a great advantage in a light type of rolling stock. The farmer, if he wanted light railways at all, wanted something that could be taken to his homestead and into his field, and nothing short of that would meet his requirements. Engineers were hoping for the development of light railways for the sake of the business which they would bring, but there was another solution of the agricultural problem, and that was the use of traction engines. He thought that those appliances had been very grossly neglected. There was only one disadvantage which they had from an engineer's point of view, and that was that, unfortunately, they only required an ordinary road to go upon. There was a very great need for making improved bridges. Many of the bridges impeded and throttled the traction traffic on ordinary roads. He believed that a great deal could be done with tramways if they were constructed in accordance with the requirements of the farmer, the brickmaker, the lime-burner and others, whose goods were of great weight but low intrinsic value. They could be run in connection with the existing railway stations, and at those places cranes could be erected for transshipping the goods into the railway trucks, and in some cases goods could be removed in bulk. He regarded the paper as an extremely valuable one.

Mr. T. W. BAKER said he sometimes heard very strong objections raised against the use of traction engines on common roads. It was said that they were objectionable to the farmer, but as a user of traction engines for twenty years, he could state that that was not the case. Both drivers and horses were now used to traction engines. The present method of obtaining legal powers for the construction of lines was cumbrous. There ought to be some better tribunal than at present existed. It had been suggested that the matter should be left entirely with the Board of Trade, but he (Mr. Baker) did not think that such a change would meet the case. An altogether new form of procedure was required. The granting of compulsory powers might be in the hands of a recognised body composed, for instance, of a nominee of the Secretary of State, a member of the Institute of Civil Engineers, and a railway expert, and the decision of that body should be made an order of Court. Any railway which was intended to meet the existing distress in agriculture must not cost more than 2500*l.* a mile; and he believed that, in order to meet the requirement, it would be absolutely necessary to use the existing roads.

General Webber, alluding to the remarks which had been made on the subject of transporting rolling stock from light railways to main lines, said that some years ago a model, illustrating a method of accomplishing that result, was to be seen at the offices of the Lancaster Waggon Company, and could no doubt still be seen there.

Mr. H. Conradi said that the authors had produced a most valuable paper, but they had not pointed out how engineers should proceed in order to induce the public authorities to remove or relax the present restrictions. Neither Parliament nor the Board of Trade nor any local authority would move in the matter of their own accord. Promoters of railway and tramway undertakings would most probably decline to expend their money for the purpose of getting the restrictions removed, as the fight would be one not only for their own cause, but for the whole country. He therefore suggested that the Society of Engineers should move in the matter in a way similar to that adopted by the Tramway Institute of Great Britain and Ireland. That body sought by legal proceedings to protect the interests of the tramway companies which had joined the Institute. He thought that the Society of Engineers could place itself in communication with all industrial and agricultural centres where public improvements were required, and get all parties interested to unite with the Society in furthering the objects in view.

Mr. Stephen Sellon, in reply, said that when Mr. Bryce told the committee on light railways that they were not to consider the question of gauge or the question of the Treasury guarantee, he showed his wisdom, for probably he supposed, firstly, that if the committee entered upon the question of gauge they would not issue any report at all during the next year, and secondly, that if they took into consideration the Treasury guarantee, they would be all so ready to accept the guarantee that they would not want to have any discussion on the matter at all. The reason that the question of Parliamentary procedure was forced upon the consideration of engineers was that a promoter, when he went to Parliament, was necessarily a very weak person. He was simply a man by himself, who had to appear before a tribunal with a scheme in which he was subject to the opposition of all parties, and he had not a voice in the proceedings beyond carrying out certain details such as were sufficient to pass the Standing Orders. He (the speaker) thought the real burden of light railways had not been borne by the proper parties, namely, the railway companies. Mr. Ackworth, a barrister, who had written a good deal on the subject, had said that the railway companies were much too busy to consider the question, and that the manager of a railway was not able to give attention to such a thing as a paltry feeder. The relaxation of the Board of Trade regulations was of little use. It was very well to suggest that those regulations should be swept away, but surely it would be wiser to amend them. His (Mr. Sellon's) opinion was that the regulations of the Board of Trade were not irksome so long as they were left to the Board of Trade itself. Unfortunately the Board of Trade had not sufficient power. The Government had always legislated for the Board of Trade, and then asked the Board to carry out the regulations. The Board of Trade had had a very severe responsibility put upon it, and that was, no doubt, the reason why the rules had been exceedingly strict. As to the promotion of a line by the local authorities, that might be all very well so long as the line was confined to one particular locality: but he had met with very great difficulties in cases in which lines had run through the districts of two or three local authorities. Each local body had its own opinion. General Hutchinson had stated before the committee on light railways, that if the obtaining of a Bill depended upon two or three different local authorities it would be absolutely impossible to get a sensible Bill passed. General Hutchinson was one of the most experienced persons in this country with regard to the disagreements of local bodies.

With regard to what had been said by General Webber as to the promotion money which had to be advanced, it must be remembered that the 10,000*l*. which had been referred to as having been spent upon the promotion of one particular line, had to be expended upon a Bill which, in the result, was not carried through, and would ultimately have to be saddled upon some other line for which the promoters might obtain a Bill in the subsequent Session. If two or three Bills were lost Session after Session, the capital expended would have to be made a burden upon the fourth line, and would amount to such a sum that it could not be expected that any profit could be got out of the line. With regard to sections, to which subject Mr. Walmisley had referred, his (Mr. Sellon's) opinion was, that the sections were only of use to the promotors. They were merely required for the purpose of estimating, and for the purpose of showing the gradients. He did not see any necessity for a frontager or a local authority to have a section of the gradients. He was sorry to hear that there was a considerable difference of opinion with regard to the question of whether the agricultural mind was sufficiently advanced to consent to money for making the light railways being found eventually out of the rates. It absolutely behoved the local authorities, or somebody, to find a guarantee for the construction of light railways, for, as Mr. Garcke had properly remarked, there was no chance of a light railway paying. If it was found that light railways would pay them, one or two good examples would satisfy the public mind. It might be true, as had been stated, that railway companies generally paid small dividends, but at the present time the share list would show that most lines stood at a very high premium, and that fact showed that they had some money somewhere, and consequently one would think that they could afford to assist in the direction of making feeders for their system.

A suggestion had been made for constituting a new tribunal for considering and passing railway Bills; but surely the most simple procedure would be that ordinarily carried out by the Local Government Board when a local authority wanted to obtain money for the purpose of making drainage or other works. The Local Government Board sent down an inspector to the locality, and he reported as to whether the central authority ought to sanction the loan or not. The Board of Trade seemed to him to be the proper authority to have charge of inquiries with regard to new railways. The rulings of that body were generally very satisfactory, and the transfer of the authority to them would reduce the cost of the procedure. Inspectors who held a local inquiry would have the advantage of seeing the district. That was an advantage which a Parliamentary Committee never had. At present long discussions, continued from day to day, took place, for the purpose of deciding questions which could be settled at once by a simple view of the locality. It was perfectly true, as had been pointed out, that the paper had dealt with only a small part of the question. If he and his co-author had dealt with the whole subject they would have never finished; and it must be borne in mind that there was now a Bill before Parliament dealing with the very subject which had been dealt with by the paper, namely, the simplification of the procedure in respect to the permission of light railways. After Parliament had decided on a particular form of procedure it would be time enough to consider the further portions of the question. As a matter of fact, there had been really very little in the discussion to be answered, as everybody had agreed more or less with the views which had been put forward on the points dealt with.

Mr. W. WORBY BEAUMONT, in reply, said that there was a prevalent opinion in the public mind that those who had taken up the subject of light railways were proposing that there should be a vast system of light railways constructed here, there and everywhere, and that a network of such lines should be made round every great centre, in order that farmers and others should be helped in some miraculous way, and that corn which was now only worth about 20*s.* a quarter should be raised to the profit-earning capacity of the same corn at something like 30*s.* a quarter, by cheap transport. It seemed to be necessary to say that engineers, as a rule, had not the slightest notion of proposing anything of the kind. All that they sought to do was to construct light railways and tramways in various places where, as there was at present reason to suppose, such facilities were necessary and would rapidly develop traffic and soon become profitable. Of course, if promoters waited until the traffic was actually ready for the lines, and until they could see the people standing by the roadsides with their baskets, and asking to be carried, they would never get any railways constructed at all. The great main lines would not have been constructed if the promoters of them had waited until everybody was satisfied that a traffic was already waiting for them. Many of the arguments against light railroads and tramroads were directed against ideas which certainly engineers had never held. Speaking generally, engineers only asked that they should be free to do certain things, firstly, to show where lines were required and where they would be likely to pay; secondly, to build lines without the existing Parliamentary restrictions, when the consent of the districts had been obtained; and thirdly, to obtain statutory powers, when required, by means of common sense and not antiquated procedure. Engineers were not interested in trying to attract attention to schemes, unless they were likely to pay. Engineers had reputations which they valued very highly, and if they saw that railways were required and might prove of very great good, they were willing to risk their reputation on what they believed to be a good thing; but none of them wanted to construct lines that would be obviously useless. The paper had abstained from dealing with such details as the question of gauge, and the kinds of locomotives to be employed, because so long as the permission to construct the lines themselves was refused, or only granted on conditions which were practically prohibitions, it would not be of any use to go into questions of detail.

April 1*st,* 1895.

WILLIAM G. PEIRCE, President, in the Chair.

PORTLAND CEMENT: SOME POINTS IN ITS TESTING, USES AND ABUSES.*

By D. B. Butler.

Portland cement, in the generally accepted sense of the term, consists of a mechanical mixture of chalk and clay (or other materials containing the requisite chemical constituents), calcined to incipient vitrefaction, the resulting clinker being reduced to a more or less impalpable powder. The chief chemical components of a good Portland cement may be said to range as follows:—

	Per cent.	Average. Per cent.
Silica	20 to 28	24
Oxide of iron and alumina	8 to 14	11
Lime	58 to 65	61·5

These generally constitute about 96 per cent. of the whole, the remainder being made up of small proportions of magnesia, sulphuric acid, alkalies, &c.

Portland cement can be manufactured from any raw materials containing the requisite chemical components, but of course its economical production depends entirely upon the ease with which these raw materials lend themselves to a thorough mechanical admixture, before being converted into a chemical compound by the agency of heat. There are natural formations containing the constituents of uncalcined Portland cement, such as are found in Cambridgeshire and elsewhere, but, generally speaking, these formations are not altogether to be depended on for uniformity, and the most reliable results are obtained from those materials which require mixing in certain proportions, so as to contain the requisite amount of the proper chemical ingredients. The materials most generally used in this country, and those which are most economically treated, are the chalks and clays found in the neighbourhood of the lower reaches of the Thames and Medway, and although the industry is extensively carried on in other parts of the country, it may be taken for granted that the greater part of the cement manufactured in England is made from the materials in the district referred to.

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* The Rawlinson Premium was awarded to the author for this paper.

The properties appertaining to cement, which it is necessary to ascertain, in order to arrive at an opinion of the constructive value of a given sample, are the following:—

(1) Soundness—viz., freedom from destructive agencies within itself, or, as it is generally termed, "blowing."
(2) Fineness of grinding.
(3) Strength, cohesive and adhesive.
(4) Time of set.

The soundness of a cement is a most important point, as it is evident that, no matter to what fineness it may be ground, or what strength it may develop at the earlier dates, if it eventually expands and disintegrates, it is not only of no value as a constructive material, but it is at once converted into a destructive agent. On this point the author would like to quote the opinion of his late principal and colleague, Mr. Henry Faija, an opinion which he fully endorses, viz., that if a cement is sound, it is almost invariably strong enough for any work in which it may be used. The soundness of a cement generally used to be considered as satisfactory if a pat, gauged with a minimum of water, and placed on a glass or other non-porous slab, showed no cracking or lifting at the edges at the expiration of seven days, either when plunged immediately into water, placed in water as soon as set, or left in the air. The author's experience is that this test is not altogether reliable, as he has known instances in which pats, treated as above, are perfectly sound and good at the expiration of seven days, and the briquettes also show a good tensile strength, but when kept for a period of twenty-eight days, both pats and briquettes have been found to show signs of disintegration. He has also known cements give perfectly satisfactory results at the expiration of twenty-eight days, and even then deteriorate at the end of a longer period. The most reliable test for the soundness of cements, in the author's opinion, is that which was introduced a few years ago by Mr. Faija, of which a full description is given in the paper read by him before the Society in 1885. It essentially consists in subjecting a freshly gauged pat to a moist heat of 100° F. until set, and afterwards placing it in warm water of 115° F. for the remainder of the twenty-four hours. The author has had a large experience of the apparatus for carrying out this test during the past ten years, and if a pat treated therein shows no signs of "blowing," the cement may be used with perfect confidence. If, on the contrary, it shows cracks or other signs of unsoundness, it is a danger signal, and the utmost caution should be used before sanctioning its use in any constructive work. Of course, the indications of unsoundness may be due to the extreme freshness of the sample, in which case it is advisable to lay it out to cool for a few days before finally deciding as to its use. If, at the end of that period, its objectionable characteristics have disappeared, it may be assumed that it would become fit for use with a little aeration; but if, on the other hand, it still "blows," it should not be used on any account, or, at all events, not until sufficiently aerated to show no signs of expansion when treated as described.

The hot test of Deval, in which the cement is immersed in water at 176° F., seems to the author to err on the side of severity, as there are very few cements manufactured at present which will bear being subjected to that test, unless, indeed, they have previously attained considerable age. Although it may be considered perfectly safe to use any cement that passes this ordeal satisfactorily, it is a little hard on the manufacturer to reject a sample that will not pass the test; for it is very certain that many cements which have been used, and have given perfectly satisfactory results in practice, would have been rejected if the Deval test had been insisted upon.

The fineness of grinding of a sample largely determines its usefulness as a constructive material, as it is well known that the finer a cement is ground, the better will be the results obtained from it when mixed with sand or aggregate. There is a growing demand for finer cement, and doubtless this is a tendency in the right direction, but in specifying finer cement, the user must not lose sight of the fact that finer cement means extra wear and tear on grinding machinery and reduced output, and therefore if an extra fine cement is required, he must expect to pay a somewhat higher price. At the same time, with other methods of grinding, there is no doubt that many manufacturers are able to keep pace with increasing demands for smaller residues. Looking back at some old testing books fifteen years ago, 20 per cent. on a 50 sieve was not an uncommon residue to find recorded; eight years ago it had been reduced to 10 per cent., and now many manufacturers ordinarily grind down to 5 per cent.

Various kinds of edge-runner mills in lieu of mill-stones have lately come into considerable use for grinding cement, and no doubt some of them perform their work economically. Apart from the economy, however, the fact remains that cement thus ground rarely contains the same proportion of impalpable powder as that ground by stones. As it is this impalpable powder which is the essential feature of the cement, this is an important matter. It is very easy to imagine a cement thus ground which may all pass through a sieve of the meshes ordinarily used in testing, and yet may contain scarcely any flour. A cement ground by mill-stones in the ordinary way, and leaving 10 per cent. on a 50 by 50 sieve, is generally equal in cementitious properties to one ground by edge-runner mills, leaving about half that residue. It therefore seems to suggest that, instead of specifying not more than a certain amount of coarse residue, the amount of impalpable powder, or "flour," to be determined by elutriation or other means, should be specified.

A matter which is often overlooked in testing a cement in this particular is the thickness of the wire of which the gauze is composed. It is obvious that if the wire of a sieve having the specified number of holes to the square inch is abnormally thick, the size of the hole will thereby be reduced, and *vice versa,* and in some instances may cause the rejection of a cement which would otherwise pass the specification.

The strength of a cement is generally ascertained by means of its resistance to a tensile strain, as being the easiest and most convenient test to carry out. It is doubtful, however, if in practical use, cement is ever subjected to this strain, and it is therefore only a comparative test. The most desirable feature to be observed in testing a cement for tensile strength, and one to which too much attention cannot be given, is the increase in strength of a given sample between the different dates of testing. It is obvious that a sample which develops a moderate strength at the earlier date, and continues to increase steadily at each subsequent date, is preferable to one which attains ninety per cent. of its strength at the seven days, and its full strength at twenty-eight days, while at the longer periods it shows a tendency to decrease. In the present methods of testing, the results obtained depend very much upon the skill of the operator, and therefore a considerable allowance should be made if the testing is to be carried out by inexperienced persons. The author well remembers one occasion a few years back when a dispute arose as to the quality of a consignment. He visited the works in company with representatives of the manufacturer and contractor, and samples were duly drawn from the bulk and taken to the works office, to be tested in the presence of the officer in charge. The operator in this instance was an ordinary bricklayer, whose chief idea seemed to be that the water should contain a certain percentage of cement, in contradistinction to the generally recognised practice, that the cement should be mixed with a certain percentage of water. With the aid, therefore, of a whitewash brush and a large trowel, the cement was reduced to the consistency of a thin cream and poured into the moulds. Needless to say there was not much difficulty in understanding the reason of its not having passed the specification, especially as in this instance the sample was very slow setting.

The correct amount of water to be used in gauging cement varies greatly, and no hard and fast rule can be laid down on this point, each cement requiring a quantity peculiar to itself, depending largely on its fineness and setting properties. In the author's testing room, the correct amount of water is considered to be added, when by ramming and shaking the cement into the moulds, the moisture just comes to the surface of the briquette. If more water than this is added an inferior result is obtained, while if a less quantity is used it is impossible to properly manipulate the cement, and therefore in this respect also an inferior result is obtained. Objections have sometimes been made with respect to beating and ramming the cement into the moulds for the purposes of testing, but the author's contention is, that the object of a laboratory test is always to obtain the best results from the cement under examination, and that being so, all reasonable methods are allowable for obtaining this object.

The disposition to specify excessive tensile strains at seven days, is not so prevalent as it was a short time back, and this is perhaps a point for congratulation. Experience shows that high strains generally require high percentages of lime, and to get the high strains sometimes asked for, it is absolutely necessary to "lime" up to the verge of "blow." In such cases extreme care is necessary in the manufacture, and only those acquainted with practical cement-making can appreciate the very small margin of lime allowable between a sound cement of high tensile strain, and an unsound one, the latter bringing all sorts of unpleasantness in its train.

The time of set of a cement is only of importance where it is either abnormally quick or abnormally slow, except of course in special cases such as tidal work, where it is desirable that cement placed in position at low water should be sufficiently set to prevent the rising tide separating it from the aggregate. The most important point, in the set of a cement, is what is generally known as its initial set, i.e., when hardening or crystallisation commences, as when this point is reached, the cement should be in its allotted position, and allowed to remain without being disturbed, otherwise the crystallisation will be arrested and the ultimate strength of the material weakened. The time of initial set should not give any trouble in practice, as it is a very simple matter for the clerk of works, or the foreman in charge, to make a small pat, and noting the time when hardening commences, take precautions accordingly.

Temperature and climatic influences play a very important part in the setting of cement. The author's attention was particularly drawn to this matter a very short time ago. A shipment of cement, which had been tested in the ordinary course before leaving England, satisfactorily passed the requirements of the specification as to set, but on reaching its destination in a hot climate, the engineer in charge complained that it set too quickly. This induced the author to institute a series of experiments to ascertain the comparative time of set at different temperatures, the results of which are given in Table I. In each series of experiments an exactly similar amount of water was used for gauging, the water being of the same temperature as the chamber in which the pats were placed, and to ensure a moist atmosphere, the bottom of the vessel was lined with a damp cloth. The cements were not in any way chosen specially for this experiment, but have been arranged in the table according to their time of initial set. The difference in setting is distinctly marked at each temperature, more especially between 40° and the normal 60°.

A test that is sometimes asked for, and which perhaps represents the more usual strain to which cement is subjected, is its resistance to crushing. Generally speaking, the crushing strain of a cement is from six to nine times its resistance to a tensile strain. It is, however, rather an inconvenient method of testing, and as a comparative test, the results are but little superior to the tensile strain. Added to this, the opportunities of error are much larger, as, if the surface of a cube at the point of contact is not perfectly true, the pressure comes on to the highest portion first, and thus crushes it in detail.

Provided the foregoing points are satisfactory, the colour of a sample does not matter so much, except of course for work that is exposed to view, when it should be of a cold blue-grey. This blue-grey colour may generally be taken as an indication of sufficient calcination, while if the sample has a yellowish tinge, it indicates the presence of underburnt cement, either on account of the general calcination having been insufficient, or else that the picking of the clinker to eliminate the unburnt portions has been carelessly carried out. If this yellow colour exists to any great extent, the presence of uncombined lime would probably cause it to give indications of expansion when treated in the Faija apparatus already mentioned.

The weight per bushel of a sample is now not often specified, as it is not much of a guide to the user as to the quality of the cement. To the manufacturer it may perhaps be of use, as it is an indication to him of the amount of calcination to which his cement had been subjected. If the density of a sample is required it is better to determine it by means of its specific gravity, which is not affected by the fineness to which a sample is ground.

The chemical analysis of a Portland cement is often of great corroborative value in estimating the properties of a sample, but the treatment which the raw materials have undergone during the process of manufacture, so largely affects the resulting cement, that an analysis should never be relied on by itself. Its chief use is in detecting the presence of an excess of any deleterious constituent, as well as in determining the amount of useful components, and this knowledge, in conjunction with the mechanical tests, enables an accurate opinion to be formed as to the future behaviour of the sample. Generally speaking, however, chemical analysis is of more value to the manufacturer than the user, as knowing the exact treatment to which the raw materials have been subjected, he is able to judge with accuracy what characteristics they should develop in mechanical testing and to regulate his mixtures accordingly. The importance of analysis is now generally recognised by manufacturers, and most firms, if they do not employ a resident chemist, at all events recognise the importance of having periodical analyses both of their raw materials and finished cement.

The uses of Portland cement are so numerous, that in a paper of this description, it is only possible to glance at them in passing. Perhaps the most valuable property is its power of setting and hardening under water, which, combined with its great strength, renders it peculiarly adaptable to pier and harbour work, where it often proves an indispensable material to the modern engineer. The theory that sea-water affects cement prejudicially caused considerable excitement a few years ago, when the failure occurred at Aberdeen, but subsequent experiments proved that with sound cement, properly manipulated, the engineer has nothing to fear from the effects of sea-water. That sea-water does attack unset Portland cement to a certain extent, the author has since proved by direct experiment. His experiments, however, seem to point to the conclusion that it is only attacked on the surface, where it is directly exposed to the action of the sea-water, and unless a concrete is extremely porous, and thus allows the sea-water to percolate freely through it, it should not have any detrimental effect. Moreover, the attacked portion in a neat cement does not extend above a quarter of an inch from the surface, the interior being totally unaffected, and although it continues for some time soft and unset, it eventually acquires a certain hardness, and forms a protective skin against further attack. It would therefore seem that slow-setting cements are not so suitable for sea-water work as the quicker setting varieties, the former giving more opportunity for the attack of the sea-water.

Cement is very extensively used in the manufacture of moulded or purpose-made materials such as paving slabs, &c. When properly manipulated, with a suitable aggregate, no more satisfactory and economical method of producing these articles can be wished for, but in this particular again, experience and manipulation play a very important part. In making this remark, the author has in mind a sea-wall and esplanade, which has come under his notice at a watering place on the south coast. The esplanade is formed entirely of concrete paving slabs, made by the local authorities, the sea-wall being composed of shingle concrete, faced with a coating of richer material, and the whole work forms a perfect example of what can be done with a cement concrete. Within a few miles, there is a work of a similar nature, carried out with exactly similar materials, but which work is considerably inferior in appearance, a result that can only be attributed to less experienced manipulation. In making paving slabs for work of this sort, it is usual to face the top and bottom with about half an inch of richer material, so as to form a more presentable appearance when laid in position, and by making this face on the under side as well, it is possible, when the top has become worn, to reverse the slab, thus doubling its period of usefulness. In such work, where appearance is of considerable importance, it is found advisable to keep the blocks sheltered from climatic influences as much as possible, and during dry weather to moisten them occasionally with water, which is found to preserve their colour to a great extent.

A use for cement, which concerns the architect perhaps more than the engineer, is plastering or rendering the walls of buildings, although a similar use of the material sometimes occurs in the case of reservoirs. In such cases it is most important that the cement should be thoroughly matured, and also that the wall or surface to be rendered should be thoroughly wetted before the plaster is applied, so that the cement shall not be deprived of any of the water necessary for its proper setting and hardening.

The abuses of cement are perhaps not quite so numerous as its uses, but the treatment which it sometimes has to undergo at the hands of inexperienced users, makes it a matter for wonder that failures are not more frequent. One of the most prolific causes of failure is insufficient attention to the setting properties of the cement under treatment. In very hot weather it is no uncommon thing for a cement to have a very quick initial set, and in using such a cement, therefore, in order to obtain its full strength, it must be mixed and in its allotted position within a very few minutes of adding the water. This often entails the mixing of very small quantities at a time, and if due precautions are not taken, a larger quantity is mixed than can be manipulated before setting commences. This generally results in the use of additional water, and the serious detriment if not total destruction of the setting properties of the cement. Many cases of failure have occurred, in which the cement being of good quality, though somewhat quick setting, points strongly to over manipulation or "killing."

Another frequent cause of unsatisfactory work is a dirty and unsuitable aggregate. The admixture of a very small proportion of dirt or loam is quite sufficient to materially deteriorate the strength of a concrete, and too much stress cannot be laid upon the necessity for seeing that all aggregates are free from any foreign dirty matter. A case of structural failure came under the notice of the author a short time back, in which the cement used was perfectly good, but the finer portions of aggregate consisted of very fine sand, so fine that sixty per cent. passed through a sieve having seventy holes per lineal inch, and eighty per cent. through a sieve having fifty holes per lineal inch. The structure of which it formed part had to bear a considerable thrust, and to aggravate matters, instead of this sand being properly mixed, large patches occurred in which there was no cement at all. In addition to this, the sand contained a considerable portion of loam or foreign matter, and it is not to be wondered at that failure resulted.

The neglect of the proper cooling or aeration of a cement is a frequent cause of trouble, and to ensure satisfactory work, proper cooling cannot be too strongly insisted upon. Of course cement may give good results when used hot from the mill, and the author has manufactured cement which has turned out satisfactorily under these conditions, but to use cement in this state is to court failure. It is sometimes specified that the manufacturer shall store the cement in his warehouse at a stated thickness of say three feet, for a certain period, and have it turned over three or four times at regular intervals before being supplied for use, but if this had to be done with the entire output of every factory it would necessitate an enormous increase in warehouse room, to cover the first cost of which would entail a largely increased price to the consumer. It is therefore advisable where cement is being used in considerable quantities, to construct temporary cooling sheds, with a good dry boarded floor, where the cement can be turned out of the sacks or barrels, and thoroughly aerated before use. It is sometimes contended that cement, even if shipped hot, cools sufficiently during transit. Although it undoubtedly does cool to a certain extent, it is doubtful if, when tightly packed in barrels, or closely stowed in sacks, it cools sufficiently to allow of its being immediately used with safety.

The exposure to extremes of temperature has perhaps more to answer for in the shape of unsatisfactory work than is generally recognised. If exposed to a summer sun immediately after being gauged, naturally a great deal of the necessary moisture is evaporated, leaving the cement without sufficient to complete the crystallisation already set up. The result frequently is that the work crumbles and shows signs of failure. On the other hand, exposure to frost acts on the water, and by expansion, destroys the surrounding concrete. The author once had occasion to investigate a case of failure in which frost was the undoubted cause of the mischief, as there was no fault to be found either with the cement, aggregate, or manner of manipulation. The concrete flooring of an outhouse in some new farm buildings was commenced late in December, and left partly completed owing to the Christmas holiday. As frost set in with unusual severity during the interval, the work was not revisited until the return of milder weather, three or four weeks afterwards, when it was found that that portion which was laid immediately before the frost, was utterly destroyed, while the portion previously laid, which had sufficiently hardened to prevent total destruction, showed signs of flaking on the top where it had been floated or trowelled. In this case the cement had to bear the blame, although the destroyed portions, afterwards relaid with the same materials, gave perfectly satisfactory results. During severe weather, therefore, proper precautions should be taken to protect freshly laid concrete from the effects of frost.

A matter which has lately attracted a large amount of attention, among those interested in the English cement industry, is the use of admixtures with the Portland cement clinker after calcination. At a meeting of manufacturers held on the 12th November, 1894, for the purpose of forming an English Cement Makers' Association, this matter of admixtures was brought forward, and one manufacturer boldly averred that a certain admixture improved the quality of Portland cement, and that his firm had therefore adopted it in their ordinary manufacture. As the outcome of this meeting, the cement trade section of the London Chamber of Commerce took the matter up and a committee has been appointed to investigate the question.

The one material about which the controversy chiefly rages is Kentish rag, a limestone of varying composition found near Maidstone. From samples of cement containing a certain addition of this limestone, which have been sent to the author for testing in the ordinary course, the results by the usual methods of mechanical testing compare favourably with average English cements, even when gauged with three parts of standard sand, though of course what results they would give without the admixture, he has had no opportunity of judging. He has, however, instituted a considerable series of experiments on the subject, extending over a lengthy period, and when these are completed he will be able to speak more definitely on the matter.

The same question of admixtures arose in Germany a few years back, where adulteration was then largely practised, and the results of experiments, carried out under the auspices of the German Cement Makers' Association, seemed to prove that admixtures of any sort detrimentally affected the cement, and, as a consequence, a resolution was passed, by which the members of that Association bound themselves not to use any admixture whatever, an exception being made in the case of gypsum, of which two per cent. was allowed to regulate the time of set. On the other hand, Professor Tetmajer of Zurich obtained very different results from those of the German Association. With certain admixtures he obtained equally good and in some cases better results than with the pure cement.

Until, therefore, we have more conclusive independent evidence in their favour, it seems questionable whether admixtures of any sort are desirable .As, however, such admixtures, and more especially Kentish rag, are easily detected by analysis, the user, at all events, has it in his power to discriminate between the ordinary calcined product and that containing an admixture.

To summarise the preceding remarks, apart from the question of admixtures, the chief points requiring attention in the use of cement, in order to obtain the best results, are the following :—

(1) Sound, well-ground cement, of steadily increasing strength.
(2) Due attention to the setting properties of the cement.
(3) Clean, well-proportioned aggregate.
(4) Proper maturing of the cement before use.
(5) Protection from extremes of temperature.

In conclusion, the author ventures the opinion that if the above points always received the amount of attention due to their importance, failures in cement work, apart from defective design, would very rarely be heard of; and if the opinions expressed in this paper, based as they are on personal experience, lead to a better general knowledge of the properties and capabilities of Portland cement, its object will be amply fulfilled.

DISCUSSION.

The PRESIDENT asked the meeting to join with him in offering a vote of thanks to Mr. Butler for his paper. Portland cement was in everyday use with all who were engaged in building construction. He felt certain that the information which they would gain from Mr. Butler's paper would be of great service, especially to the younger members of the Society.

The vote of thanks was accorded unanimously.

Mr. W. H. STANGER, in opening the discussion, said he trusted the author would not object to his taking exception to the statement in the paper, "that the object of a laboratory test is always to obtain the best results from the cement under examination, and that being so, all reasonable methods are allowable for obtaining this object." He was under the impression that the author and others, who were professionally engaged in the testing of cement, and who not infrequently acted as judges between manufacturers and users, preferred to make their tests approximate, as nearly as was possible in the laboratory, the conditions which were likely to obtain in actual practice on works. He therefore thought it was a little unfortunate that Mr. Butler, with his extensive experience and considerable influence in this matter, should set it forth that it was the function of a laboratory test to favour the cement, and —by inference—the manufacture. He contended that when a man was in the position of a judge he should be absolutely impartial. Engineers would immensely facilitate the manufacturer of Portland cement, if they would decide upon certain standard requirements, such as the maximum percentage of residue upon sieves of a definite number of holes per square inch, and formed of wires of definite size.

He had hoped to hear from Mr. Butler a fuller statement upon the question of the admixture of foreign materials with pure Portland cement clinker. That matter was of extreme interest, not only to manufacturers but to engineers, and he regretted that, for reasons well known to many of his hearers, he was unable as yet to give any information upon that subject. It would be extremely valuable if independent investigators, such as the author, would bring their powers to bear on that point, and let those who were for the moment intimately and personally engaged in the investigation, know what their results were. Much advantage was to be obtained by independent research in the matter, and he hoped that as soon as the author had obtained any definite results he would favour him (Mr. Stanger) with them. It behoved all who were concerned in the matter to come to some definite conclusion as to what Portland cement was, and when they had decided upon that to take care that they got it. He was afraid that it was not yet sufficiently understood that the manufacture of Portland cement was an extremely delicate chemical process, and that every properly equipped cement works ought to have on its staff a specially trained chemist constantly engaged upon the examination of the materials, in all stages from the chalk and clay pits to the finished product. Manufacturers needed to be far more careful than they generally were, as far as his experience went, in the very simple matter of picking the clinker. Improvement in that direction would cost little, and would go far towards saving manufacturers from the inconvenience and loss which unfortunately he, with others similarly engaged, not unfrequently was compelled to inflict upon them.

Mr. LEEDHAM WHITE said that with respect to the admixture of different materials with Portland cement, he was absolutely tongue-tied, as being one of the committee appointed by the London Chamber of Commerce which was at present investigating the matter through certain eminent experts, and who proposed also to call other experts to give their testimony as to the effect of such admixtures. There were, however, one or two points in the paper on which he should like to comment briefly. In the first place he would congratulate the author on his common-sense remarks as to the unfounded scare, which originated some years ago, about good Portland cement, or rather concrete, not standing the action of sea-water. The fact remained that, whatever theories might have been originated in the last few years, thousands upon thousands of tons of concrete had been used in different parts of the world and had stood the action of sea-water for more than a generation without any apparent deterioration. Engineers need not be uneasy about that most important point.

Another interesting question raised by Mr. Butler was the effect of temperature on the setting of Portland cement. He would strongly endorse Mr. Butler's remarks upon the subject, and even go somewhat farther. It was, no doubt, also absolutely true that cement set very quickly in hot climates, but Mr. Butler had omitted a fact which was just as true and possibly even more important, that cement which had been reduced by aeration to a properly stale condition before shipment, would, if shipped across the ocean in steamers (particularly such steamers as the ocean greyhounds, in which there were eighty or a hundred furnaces at work, and in which it was exposed to a temperature of at least 100 degrees), arrive on the other side in a much quicker state of setting than when it left the mills. Last year he made some tests on the American continent with cement manufactured by his Company which had been shipped in a reasonably cool condition from Great Britain. That cement was capable of being gauged when it left the works with between 18 and 19 per cent. of water, but after it had undergone the ocean voyage it could not be properly manipulated until about 26 per cent. of water had been mixed with it, all the water which had previously entered into combination with the lime of the cement having been driven off by the high temperature to which that cement had been exposed. Those two things explained what to many engineers had been an enigma, namely, the reason why tests made on the other side of the ocean very often failed to coincide with tests made in England. It was obvious that if cement arrived in that quick-setting state in which it required so large an amount of water to manipulate it, a briquette of cement would contain so much extra water instead of so much cement, and the consequence was that the briquette, when tested, would not stand the strain which a briquette with a smaller proportion of water would stand. It also proved that no amount of aeration on this side of the ocean would ensure cement shipped on steamers always arriving on the other side in proper condition. If consumers on the American continent and in many other parts of the world wished to deal fairly with cement imported by steamer before testing it, they ought not to be satisfied with the fact of the cement having been shipped in good condition originally, but they ought to lay it out and cool it and aerate it before testing it. Unless they did that they would not find such cement in as perfect a condition as that in which English testers were accustomed to find it.

Mr. Butler had pointed out the significant fact that ragstone and almost all the other ingredients which could be mixed with cement could be easily detected by chemical analysis. An analysis of a simple character would immediately disclose the fact whether Kentish rag had been mixed with Portland cement. So with regard to nearly all the other substances with which he was acquainted, unless they were used in infinitesimal quantities. Engineers might make their minds perfectly easy on that point. They had a very simple remedy in their own hands. They could first of all forbid in their specifications the use of Kentish rag and similar materials, and they could also, by ordinary chemical analyses, detect whether such admixture had been practised with regard to the cement with which they were dealing. As a manufacturer, he wished to express his thanks to the author of the paper. He might be allowed to add that all those present would very much regret the death of Mr. Faija. That gentleman had rendered important services to makers and users of cement, and had made most valuable contributions to the general enlightenment of the public, scientific and otherwise, as to its properties and treatment. They must all be glad that Mr. Faija had been succeeded by a gentleman like Mr. Butler, who appeared to be so thoroughly trained in the same school and to be ready to walk in Mr. Faija's footsteps.

Mr. J. L. Spoor congratulated the author upon his very common-sense paper. From the tone of the discussion it would seem that Kentish rag was almost a forbidden subject. Perhaps it was rather difficult to properly discuss that question in a paper like that which had been read, before the presentation of the report of the experts who had been appointed to investigate the subject on behalf of the cement-makers. He might, however, throw out the hint that it would be useful to cement-makers and to engineers if, when the aforesaid experts had submitted their report to the cement-makers, the latter could arrange to have a joint discussion with the engineers and come to some definite conclusion as to what should be done in the matter. Portland cement was, of course, a very important material from an engineering point of view, and for years they had known exactly what it was. A great many of the most important buildings owed their entire safety to Portland cement as a constructive material, and any change which might be made in that material ought not to be made until the change had been thoroughly and clearly explained and agreed to. He should have preferred that Mr. Butler should have given given some clearer formula as to what Portland cement was. The tacit agreement at present was that it should be a fairly definite mixture of carbonate of lime and clay, or silicate of alumina, and the limits had been very carefully defined. There was a French, German and English formula with which, practically, all agreed. Within the limits of that formula Portland cement must be made if it was to be safe and good.

The Kentish rag question was a very old one, and he believed that when they got the result of the investigations it would confirm the general result of European opinion. That opinion had been embodied in the standards of Germany, Austria, Switzerland, Norway and Denmark; and although, unfortunately, they had no standard specification in England, he believed that it was a common agreement that there should be no such admixture. He hoped also that when they came to the question of using gypsum, there would be a very careful agreement before that substance was added to Portland cement. He observed that a great many cement-makers were taking it for granted, that, because gypsum was used in Germany, it was a perfectly safe and reliable material. He did not quite see, on principle, why those makers who were adding Kentish rag to their cement should be pilloried, and why makers who were adding another material should go scot free. It must not be taken so easily for granted that gypsum was a perfectly reliable addition. Even the Germans themselves, who had for years been adding gypsum, were now finding what many English makers had known for years, namely, that although adding up to 2 per cent. of sulphate of lime in the form of gypsum to cement regulated its setting, yet they were also finding something which had a very significant bearing on Mr. White's remarks, namely, that when cement to which the gypsum had been added was laid down in the warehouse, and kept for weeks and months, the cement became as quick or quicker than it was before the gypsum was added. That fact was calculated to make them pause before they added such a very dangerous article as sulphate of lime to their cement.

It was significant that the author had omitted all reference to a standard specification. No one could point to any authoritative standard in England as to what Portland cement really was, or what its chemical constituents should be within absolutely definite limits. With the exception perhaps of the United States no other country was in a similar position. The life of the cement-makers at the present time was not one of the most pleasant character. It was a perpetual egg-dance amongst specifications which, in a great many instances, it was utterly impossible to fulfil honestly. Almost every engineer had a specification of his own; and yet, after all, engineers did not know so much about cement as cement-makers did. He thought that it would benefit everybody if engineers would consult cement-makers as to what was the best cement for them to use. The German makers, with a good deal of common sense, went to the engineers and pointed out what cement they ought to have; and the result of that practice had been that the standard cement of Germany was an excellent one. English makers could and did produce a cement which was as good as anything that was made anywhere else in the world, but they only made such cement when they were asked for it. Let cement-makers get a standard specification and rid themselves of all the dancing about and trying to please engineers who very often asked for the impossible. He believed that if a minimum standard was agreed upon, cement-makers would try to excel each other and pass the specification.

He was afraid Mr. Butler had not quite sufficient data with regard to cement ground in edge-runner mills. He believed the question of fineness of the ultimate particle was not inherent in any method of grinding. It was purely a question of sifting, as far as his experience went. There was no absolute rule that cement from edge-runner mills or mills of the Askham type should be coarser than cement ground in mill-stones. From a manufacturing point of view it was cheaper to grind in other machines than mill-stones. But there was the very important advantage in grinding in edge-runner mills, ball mills and Askham mills, that the cement on leaving the mill was practically cool. Makers would generally admit that that was a very great advantage in every way. He had listened to the paper with very great pleasure, and he must compliment Mr. Butler on the very common-sense and practical exposition which he had given of his views.

Mr. A. W. Ackermann, referring to the use of cement abroad which had been exported from England, said he had found it was undesirable to convey the material in casks, unless of specially strong and sound manufacture. If good on shipping, it was impossible to say how it would arrive at the works abroad, and he had found it to be frequently unfit for any use, due to air slaking, damp, and at times to loss by leakage. If, however, the cement was sent out in iron tanks or drums, and was, after opening up, carefully aired before use, it was a very valuable material. One of the great troubles in connection with the use of Portland cement in tropical or semi-tropical climates, was the setting: it did not get a chance of slowly setting; slow setting he had always found to give the best results. The trouble named was due to rapid evaporation of the water added, to an extent quite unappreciated in an English climate. Success could only be secured by keeping the work well moistened and protected from the sun. He had been consulted about cement work which appeared so rotten that it was a question of throwing all the work down and commencing *de novo*. He had recommended that the work should first be well watered and allowed time: the result was satisfactory, the work was saved. At the end of three or four months, he had generally found, if cement set slowly it set well. Rapid setting cements were always a trouble in hot climates. He had made several experiments on the subject, and had found the addition of hydrochloric acid in very small doses to the mixing water retarded the drying or evaporating action.

As to testing cement in the Colonies, the great difficulty was to persuade any of the importers to have it tested. They say they do not want to test it, but to sell it. The carriage of cement to a great distance was a very great item in its ultimate cost. The addition to it of any materials which would increase its bulk or weight, would tell very much against the manufacturers in limiting its use. He had paid 35*s.* a cask for cement within half a mile of the ship's side; and at 700 miles farther inland it would cost from 4*l.* to 5*l.* a cask of 400 lbs.

If English manufacturers added anything to the cement to increase the bulk or weight, the Germans, he believed, would have a very good chance abroad; they were already exporting at rather less than English prices, and he had used very good German cement in the Colonies. If the weight and bulk could be reduced, and its power of carrying aggregates increased, its use abroad would largely extend to places where the cost of carriage now precluded its use. Engineers would not hesitate to pay a higher price per cask or tank for a concentrated cement. He believed in the Colonies there would be an opening for 100-lb. casks or drums. Farmers hesitated to pay 20*s.* for a 400-lb. cask, when 100 lbs. would be more than they required for repairs, to say nothing of carrying a useless 300 lbs. hundreds of miles.

He had always been an advocate for the use of cement in preference to lime, being less bulky to carry and resulting in far sounder work. For mortar, about 8 to 1, he found the limit, if more sand was used the mortar would not cling to the trowel, and even at that some men complained, so that there was but little fear that the cement would be stinted. He had found it actually cheaper than many local limes, and far superior. He was glad to hear the author of the paper did not agree with the practice of adding clay. He had no doubt some of the members of the Society remembered that the late Mr. Edwin A. Bernays, who had very extensive experience with cement, was a great advocate for adding a small quantity of clay to concrete, and he undoubtedly executed some very splendid work with such mixture. He (Mr. Ackermann) had tried the same experiment himself, and it resulted in total failure, and he advocated a clean aggregate. He had used cement in the building of a large brewery, and the floors all went wrong; the cement was tested time after time, its goodness did not justify the failure. Ultimately he found that it was caused by the presence of beer and yeast, which prevented the cement setting.

Mr. P. J. Neate, referring to the limiting percentages of components of a Portland cement referred to by the author at the commencement of his paper, said he must raise a protest against the lower limit of lime, which was put at 58 per cent. A fair analysis of Roman cement showed 56·5 per cent. of lime, and such a cement would give but 90 lbs. per square inch tensile stress at seven days. The author's mean of 61·5 was much nearer the lower limit for modern manufactures, unadulterated by fire-brick or other silicious or argillaceous additions. Magnesia cement was, or ought to be, an exception, but that material was quite *sui generis*, of extremely limited production, and need not be considered. As to edge-runner grinding mills, the author's remark as to the ease of imagining a sample thus ground with scarcely any flour, savoured more of the laboratory than of the factory. The fact was, that gold-mining engineers had been fruitlessly striving for years to produce such a sample, which, to the manufacturer beset with technical difficulties, was practically unimaginable. The opinion expressed as to the relative equivalent fineness of edge-runner and mill-stone cements was about correct, 6 per cent. on a fifty for edge mills being probably more nearly equivalent to 10 per cent. with mill-stones. That comparison, however, only held good when the mill-stones were unassisted by sieves or separators. When either of the latter was extensively used the edge-mill frequently gave the best results. That reminded him of a "take-down" he once got in a remote provincial cement-works. He had submitted a sample of edge-runner ground cement for inspection, which the works manager carefully sifted on a fifty-mesh sieve, and then, to his surprise, he threw away the residue almost unexamined. He (Mr. Neate) began a remonstrance, but the comical smile on the manager's face as he sampled the fine sifting with his finger and thumb, quickly changed the rebuke into a compliment.

The tendency in favour of fine grinding continued, and foreign nations were much ahead of us in that respect. That was one of the chief reasons why the Germans had secured so large a share of our United States trade, but fortunately English makers had realised their danger, and were rapidly imitating their hitherto despised competitors. His own practice was to grind the whole of his output with edge-runners, and reduce it all to about ½ per cent. on a fifty mesh, and 6 to 7 per cent. on a seventy-six mesh sieve. That could be done at considerably less cost than was involved in grinding cement containing 10 per cent. residue on a fifty-mesh sieve by mill-stones. He was confident that the elutriation test would be too complicated and difficult of standardisation for acceptance either by manufacturers or users, and he firmly believed that a 100 linear mesh sieve would give all requisite information. He had placed under the microscope some particles of cement residue, about $\frac{1}{200}$ of an inch in diameter originally, which had had about three years in water and one in air, and found that they were thoroughly cemented together, the original angular forms being practically obliterated.

The author's experiences with the bricklayer cement gauger raised the important question of a reference or arbitration clause in case of disputed tests. Such a clause ought to be inserted in all cement contracts, not only as a protection for the manufacturers against ignorance, but as a means of removing the temptation to which subordinate officials were occasionally exposed, of rejecting a really good sample from improper motives.

He could not agree with the author's definition of the initial set, as he held that crystals began forming the instant sufficient water was added. The crystals increased in size around suitable nuclei until they began to interlock, when their mobility was arrested, and initial set commenced. If undisturbed, the crystals soon became thick and strong, eventually bonding into a solid mass if a suitable quantity of water had been added. In testing the compressive resistance of a series of cubes of chalk of various qualities, he recently met with the same troubles as the author, due to crushing in detail. He found, however, that it was the corners which generally yielded first, owing to their want of lateral support, and he proposed to make future tests with cylinders instead of cubes. He believed also that more uniform tensile results could be obtained with briquettes of cylindrical instead of rectangular cross section, for similar reasons. The author in his paper several times stated that the cement should be "cool," and it might therefore be inferred that hot cement was usually unfit for use. In the old days of mill-stones, when cement was raised by them to over 200° F., coolness was a fair guarantee of aeration, and aeration was a necessity, because, with the crude methods which were then in vogue, occasional overliming and frequent underburning were inevitable. At the present time more care was taken, and certainly a large proportion of the cement made by the more skilful manufacturers was fit to be used at once, without danger. On the other hand, as edge-runners raised the temperature of the cement but slightly, coolness was no longer a guarantee of aeration. His belief was that Kentish rag acted beneficially upon cement by hydrating any small excess of free lime that might be present through overliming and underburning; and his theory had been confirmed by a cement-maker who habitually used that ingredient, and who stated that his cement was always fit to be used at once, and never required the customary turning over, or maturing, so frequently desirable with the so-called unadulterated article.

Mr. BERTRAM BLOUNT endorsed the view that the manufacture of cement was a distinctly chemical operation. It was, indeed, a very delicate operation at that. He must take exception, as the last speaker did, but on a different ground, to the composition of cement as given by the author at the beginning of his paper. The silica was put down as ranging from 20 to 28 per cent., and the average was given as 24 per cent. The so-called average of 24 per cent. was evidently only the mean between the two extremes 20 and 28 per cent.; it did not follow that 24 per cent. was the average of ordinary cement, and as a matter of fact it was not so. The true average was perceptibly lower, and a percentage as high as 24 would be found a most inconvenient one for both maker and user, as it would inevitably lead to the production of an article inferior to that habitually made. He conceived that the error had crept in in consequence of a confusion between the amount of silica in cement which was present in an active and soluble state and that which was present as an absolutely inert residue. In the ordinary routine of analysis silica was got out associated with those silicates which had never been thoroughly fluxed by the action of the lime during the process of clinkering. The insoluble residue was very commonly lumped with the active silica and was returned as forming part of it. Certainly, in his experience, 24 per cent. of silica was decidedly too high to be taken as an average.

The author's statement relating to the use of the hot test devised by Deval, was not devoid of interest of a very practical kind. He (Mr. Blount) had used that test in his own practice and believed that he might claim to have introduced it into this country. Such results as he had been able to collect led him to suppose that justice had scarcely been done to that test in the paper. Although it was perfectly true that a great many cements, as at present manufactured, failed to comply with the Deval test, yet he was happy to say that among the cement-makers there were already some who turned out cements of such excellent quality that they complied with its requirements easily. Moreover, the test had in addition a different function altogether. It not only sufficed as a criterion of the value of cement, but it was also most useful in the hands of the tester as to the quality of raw materials for cement-making, and the value of the cement which would be prepared from them. One point which had been already touched upon by previous speakers he could not forbear emphasising. The author said, "Objections have sometimes been made with respect to beating and ramming the cement into the moulds for the purposes of testing, but the author's contention is that the object of a laboratory test is always to obtain the best results from the cement under examination, and, that being so, all reasonable methods are allowable for obtaining this object." That might be taken to apply equally to every other test to which cement was put when its value as a marketable article was appraised, and as a tester and analyst of cement he ventured to think that it was his duty not to get the best results that could be obtained, but to get fair results, for his position was that of a judge, and the attitude of a judge was very properly one of impartiality.

There was a further point connected with the use of a compression instead of a tensile test for determining the strength of cement, which claimed comment. Mr. Butler stated that a compression test was not altogether to be preferred to a tensile test, as there was difficulty in allowing the crushing to take place entirely over the section of the testing piece. Without entering into the question of compressive *v.* tensile tests, he would say that that difficulty could be quite readily overcome. Every engineer knew that it was a very common practice to put the material to be tested in compression in some plastic bedding. As a matter of fact, plaster of Paris was the most usual material employed in this way for cement testing; and when a plane surface had been obtained by a bedding of that description there was no reason why the strain should not be applied in a perfectly uniform manner. The occurrence of the well-known double-pyramid shape given by cement compression test cubes (in common with most other materials) on crushing was a clear indication that the strain had been applied in a perfectly equable manner. Therefore he did not think that the point raised by the author was of very much importance. He was much gratified by Mr. Butler's excellent endorsement of the view which he (Mr. Blount) had long been upholding with regard to the value of the test known as the specific gravity test, as opposed to the now somewhat obsolete weight-per-bushel test. When he first suggested that test he was more or less laughed at—of course kindly laughed at—and it was a matter of no small pleasure to him to find such weighty corroboration of his views. He believed that the use of the specific gravity test, as opposed to cruder methods, would shortly become general. The determination of the specific gravity would afford an exact criterion in place of a rough and ready and altogether imperfect method of discrimination.

With regard to chemical analysis, it was stated in the paper that analysis was useful to the manufacturer rather than to the user. He was anxious to uphold the validity of chemical analysis for the purpose not merely of informing the manufacturer what the nature of his product was, but of possessing a wider utility. The function of chemical analysis not only embraced the guidance of the manufacturer in the selection of his materials and the proper method of converting them into finished cement of good quality, but it also covered those cases in which the user was not absolutely certain as to the quality of the cement which was supplied to him. He (the speaker) would be the last to uphold the substitution of analysis for mechanical testing, to the exclusion of the latter, for he believed implicitly in the need for both, and he certainly thought that unless the two methods were used discreetly and in conjunction with each other, half the value of each test disappeared. The need, however, for habitual analysis, in addition to the usual mechanical tests, was now greater than ever, because many tales were now current of admixtures of a more or less alarming kind. Analysis enabled those who required a certain defined admixture and no other, or who wanted no admixture whatever, to obtain precisely what they needed. There was no doubt that if buyers would only state their requirements they would be able to get them supplied. The old ghost of magnesia had been effectually laid years ago and need not be disturbed.

The use of the word "cool," adopted in the paper, was general, but unfortunate, for in fact it meant nothing whatever. The actual fall of the temperature of cement, after it had come through the stones or from the edge-runners, or from whatever comminuting machinery was used, had nothing whatever to do with the real amount of aeration which the cement had undergone. It was a little to be regretted that that part of the paper which dealt with this subject scarcely made the point as clear as could be wished.

Mr. V. DE MICHELE said that he concurred in almost everything which had been stated by Mr. Butler in his able paper, and he thought that the author had made most valuable points. The author mentioned that when there was a yellow colour in cement it was due to want of picking. He (Mr. Michele) thought, however, that it was more often due to the presence of an excess of clay. With regard to specific gravity, he thought that it had been generally accepted of late as being the right test. He supported what Mr. Butler said about the great importance of the expansion test. He thought that that should be the first test of all with regard to cement. The tensile and other tests all came after the expansion test.

Mr. G. A. GOODWIN said that the question of the so-called adulteration of cement by ragstone, which was discussed at the well-known Cannon Street meeting, had done a large amount of injury to the English trade. He could not divulge names, but some clients had told him that since what took place at that meeting had been known in the Colonies, instructions had been received not to ship any more cement from England until the question of adulteration had been settled. He had recently become acquainted with German cement and the systems of German manufacture, and he found that in many respects they were ahead of English. It was not an uncommon thing in Germany for the cement to be sifted through a sieve having 5805 holes to the square inch (that was an odd number because it had been worked from centimetre measurements) leaving a residue of only two per cent., which was very small. With 32,250 they got 23·7 per cent. The hot-water test which Mr. Butler had referred to as being 115 degrees, was increased to 122 degrees, and yet they obtained a satisfactory result. The thickness of the wire had been referred to, and he would ask the author whether he could state what proportion they should have compared with the size of the opening of the mesh. He (the author) expressed the opinion that the wires should be half the width of the opening. Taking a mesh of fifty holes to the lineal inch, the wires should be $\frac{1}{150}$ of an inch in diameter, while the spaces would be $\frac{1}{75}$, or considerably less than appeared on the surface when they talked of a fifty mesh.

His experience of the testing of materials, which had been considerable, led him to differ from those who stated that the test of a material should not represent the best results that could be got out of it. He thought that what all engineers wanted to know was, the actual inherent quality of the material. It then devolved upon the engineer to see that the results approximated as closely as possible to those that were obtained in the laboratory. It had also been suggested that the tests should be carried out under the same conditions as applied when it was in actual use, but it would frequently be impossible to do this; for instance, take as an example an iron or steel structure such as a bridge, it would not be practicable to test the material forming it, while under a constant state of vibration. Materials for such structures were tested carefully in the ordinary way in a quiescent state, and the best results were thus obtained; known factors of safety were then used to give the required surplus strength.

He was pleased that no one except himself (and he apologised for himself) had used the word "adulteration," because whether Kentish rag was an adulteration or not, was the special point that the Commission would have to determine. He was not a chemist, but it had occurred to him that the admixture of

Kentish rag ground very much finer than the cement itself, might be of use in helping to fill up the spaces between the ground atoms of the cement. By the use of the fine ragstone a larger surface of the cement might be brought into contact.

As to the German Association, he would read to the meeting the agreement that was entered into by the Union of German Portland Cement Manufacturers. He thought that would be of interest to the manufacturers of this country.

"(*a*) The members of the Union of German Portland Cement Manufacturers engage to bring into the trade under the denomination of Portland Cement only a product formed from a thorough mixture of limestone and clayey substances forming the material body of a clinker, calcined to incipient vitrefaction and reduced to a fine meal. Any product arising in any other method than that stated above, or to which foreign bodies are added either during or before the drying, will not be acknowledged by them as Portland cement, but rather, the sale of such products under the term "Portland Cement" will be considered as an imposition on the buyer. This declaration has no reference to trifling additions made for regulating the binding of Portland cement, and which are allowed up to the extent of 2 per cent.

(*b*) Any member acting contrary to the obligation taken upon himself shall be excluded from the Association and his expulsion made public.

(*c*) The members, in giving this declaration, acknowledge the duty of the Committee of the Union to see that the obligations entered into are strictly adhered to. *Berlin*, 1888."

In the last paragraph of his paper Mr. Butler remarked that if the points brought out by him always received the amount of attention due to their importance, failures in cement work, apart from defective design, would very rarely be heard of. He (Mr. Goodwin) thought the author should have said, "would never be heard of."

Mr. W. WORBY BEAUMONT said that the author had referred to grinding by grindstones and by edge-runners, and inferentially he had referred to roller mills for grinding the clinker. It seemed strange to him that, with all the knowledge which was possessed of the advantage of separating work into several stages, so much should be done as was done, even now, in cement works in smashing and grinding the clinker in one operation. He had often felt that in cement works there was not sufficient attention paid to the use of the stone-breaker or crusher, and that instead of passing the clinker through one machine it would often pay to have three machines, each performing a certain stage in the operation of reducing the materials to the size which should pass—say from the third machine—either to the mill-stones or to the edge-runners. At the present time the wear and tear of the edge-runners or the roller mills was very much greater than it would be if the process was reduced to stages, and although the first cost of the plant would be much larger than it was now, the reduction in the cost of repairs and also in the power necessary would be much greater than was usually supposed. He would ask those present who were interested from a mechanical point of view to give the meeting their experience on the wear of mill-stones and machines by the very rough system at present generally adopted as compared with the greater duty and lower wear and tear which he believed would result from the use of more extensive division of the processes amongst several machines, instead of two. He thought that it would pay to make three different grade crushings and separations by suitable machines, before the tailings from the third separation reached the first edge-runners, and each edge-runner should have only a definite fraction of the whole work to do.

Mr. W. P. Morison wished to know whether the author, in saying that it was not usual to specify the weight of cement, meant to imply that the specific gravity was now specified in lieu of the weight per striked bushel? He (Mr. Morison) was under the impression that the weight of cement was an important guide as to its sufficient calcination, which was a very important feature in its manufacture. Some form of ascertaining the weight should be provided for. It had been said that the magnesia ghost had been laid, but he thought it was very desirable that some statement should be made as to what proportion of magnesia would be admissible in cement without injury. After all, although sea-water might not be injurious to cement, the wall at Aberdeen did fall, and from his reading of the reports on the subject he thought that the failure was due to the concrete not being sufficiently strong for its situation, and to some action of the sea-water upon the magnesia in the cement. He understood that about 3 per cent. of magnesia was the highest proportion admissible. Another question which had been raised was that of having a standard specification for cement. He apprehended, however, that it was the duty of the engineer to specify what he required, and that some discretion must be left to him.

Mr. H. Stopes said that Mr. Ackermann had stated that he had used cement in brewery work, and that it had been unsuccessful in consequence of the action of the beer. As there was a prejudice in the minds of many against the use of cement for brewery work, he thought that it was only fair to manufacturers to state that if proper care was taken to use good cement and a suitable aggregate was used, such, for instance, as crushed clean granite, no other material would better stand brewery work or better withstand the wear and tear of casks in every form. A properly laid cement concrete floor would resist the action of beer better than York stone itself.

Mr. W. R. Craske, referring to a previous discusion at a meeting of the Society upon the failure of the wall at Aberdeen, said that the idea of the failure having been due to defective cement was negatived in that discussion, inasmuch as if the cement had been defective, there must have been collusion between the cement manufacturer and the clerk of the works or the person who tested the cement, and that was a conclusion which they could not for one moment admit. It was proved conclusively at the meeting that the aggregate which had been used in that structure was beach pebbles, which was a most imperfect one. Two or three persons testified to having seen large stones of eight or ten inches in diameter in the aggregate, and those consequently made a very porous concrete through which the water trickled at each inflow and ebb of the tide, and the consequence was that the concrete was gradually frittered away. He did not think that the conclusion arrived at at the meeting to which he had referred had been upset yet. Another speaker had stated that the late Mr. Edwin A. Bernays had recommended the admixture of a little clay in the aggregate. Mr. Bernays's formula was loam, and what he referred to as loam was Aylesford sand, which was not clay at all. It was a soft sand, and was mixed with the Thames ballast, of which the aggregate chiefly consisted. That fact would perhaps give the speaker who had referred to that point a different view as to the use of clay from that which he entertained at the present time. He (Mr. Craske) was not prepared to defend Mr. Butler's remarks with regard to obtaining the very best results. Mr. Butler was perhaps unfortunate in the use of the term "best results." Perhaps he ought to have said "the true results," or "the fair results," and he hoped Mr. Butler would adopt one of these expressions.

Mr. S. Sellon said that, supposing cement had arrived at an absolute state of perfection, and no improvement could be anticipated in the future, they might accept the view that there ought to be such a thing as a standard specification. But he very much doubted whether manufacturers who had to vie with one another in regard to the quality of cement, would care to have such a thing as a standard specification. One speaker had referred to what he (Mr. Sellon) regarded as an exceedingly dangerous doctrine, and had suggested that when an engineer sent to a professional expert to give him the qualities of a particular cement, the expert should give the engineer what, in his opinion, were the fair results, constituting himself, therefore, the judge, and leaving the engineer out of the question altogether. His (Mr. Sellon's) opinion was, that the engineer was to be the judge, and that it was for the professional expert to give him the exact qualities which he required and asked for. It had been suggested that the manufacturer should be taken into the confidence of the engineer. He (Mr. Sellon) would rather put himself in communication with the manufacturer and get an article from him which he might depend upon, if such a doctrine was carried out generally by professional experts, for in one case he should be getting an article from a responsible manufacturer, and in the other case he should be getting a report from an irresponsible expert. He could not help thinking that, taking cement manufacturers as a whole, engineers were very well served.

Mr. D. B. Butler commenced his reply by thanking the meeting for the very kind way in which they had received the paper. With reference to ramming and beating the cement into the moulds for the purposes of testing, objections had been raised to the statement that the object of a laboratory test was always to obtain the best results from the sample under examination. That statement of course referred solely to the making of briquettes, &c., and on that point he was supported by the opinion of the late Mr. Faija. If the best results were obtained the user would know what the sample was capable of under the most favourable conditions, and could make his dispositions accordingly. The inference, therefore, of one speaker, that the cement was to be favoured in every test to which it was subjected, seemed to him rather ridiculous, and he failed to see how the sentence in question could be made to bear such a construction.

With regard to the different specifications which had been referred to, he might state that Mr. Faija some years ago tried to get out a standard specification, but, owing to the very small amount of support which he received from manufacturers and engineers generally, the matter had to be dropped.

He was glad Mr. Stanger agreed with him as to the value of chemistry in the manufacture of cement. Cement-making was an operation requiring much more care and attention to details than was generally recognised, and was not the mere lumping together of so many tons of raw materials, as might be supposed. As stated in the paper, only those who, like himself, had had practical charge of cement-works could appreciate the careful attention required.

The remarks of Mr. Leedham White, as to cement being thoroughly matured before leaving England, and then getting hot again on its passage out in the steamer, were very interesting. All who had to do with cement would agree that the older a cement was, the more water it required to gauge it properly, but, allowing for differences of atmospheric temperature, he could not quite understand how the cement could have been sufficiently heated in the steamer to neutralise the effect of the maturing before shipment.

The admixture of Kentish rag was, as had been stated, very easily detected by chemical means. Kentish rag, being a carbonate of lime, would effervesce strongly on the addition of hydrochloric acid, and therefore a cement containing any appreciable quantity would exhibit similar characteristics, according to the amount of admixture it contained. That effervescence, however, must not be confounded with the slight effervescence due to the carbonic acid absorbed by the cement during maturing or aeration. All well-matured cements, or those that had attained any age, effervesce more or less on the addition of hydrochloric acid, but in the case of an admixture of Kentish rag, the effervescence was markedly different, the coarser ground particles of the limestone floating about in the liquid, and giving off gas.

With regard to the remarks of Mr. Spoor, he would call attention to the definition of cement which he had given at the commencement of the paper. Mr. Spoor did not quite agree with him as to the difference of the cementitious properties of cement ground by edge-runner mills and that ground by millstones, but Mr. Neate, who had had much experience in the matter, seemed to agree that cement ground with millstones leaving 10 per cent. on a 50 sieve, was equal to cement ground with edge-runner mills leaving 6 per cent. Mr. Neate said he had put in the reservation providing that the millstones were worked without sieves or separators. That qualification had escaped his (Mr. Butler's) notice, but even then he should be inclined to stick to his original statement. With regard to the elutriation test for determining the exact amount of impalpable flour or powder in the cement, that was a matter upon which he was at present making experiments.

He was glad that Mr. Blount agreed with him, that analysis should never be taken by itself in estimating the constructive value of cement. Analysis would show whether the cement contained the proper ingredients, but it would not determine whether those ingredients had been properly treated during the process of manufacture, which was the most vital point of all. With reference to the Deval hot test, Mr. Blount admitted that a great many of the cements made in this country would not pass that test, while he claimed superexcellence for those cements that withstood it. He (Mr. Butler) was of opinion that it was altogether too severe, and moreover that it tended to favour over-clayed cements. He assisted the late Mr. Faija some fourteen years ago in his experiments as to the most advisable temperatures to use in his (Mr. Faija's) apparatus, and it was found that from 115° to 118° F. were the most suitable. Any higher temperature tended to needlessly condemn cements that gave perfectly satisfactory results in practice. As to the word "cool," perhaps it was hardly the right word to be used as he had used it in the paper, perhaps "matured" would be the better term.

He quite agreed with Mr. Beaumont as to the advisability of a gradual reduction process in the grinding of cement, instead of leaving so much for the millstones to do, and he knew of several works in which some such process had been adopted with success.

In conclusion, he again thanked the meeting for the favourable reception they had accorded him, and trusted his remarks would be of practical value to all interested in the subject.

TABLE I.

INFLUENCE OF TEMPERATURE ON THE SETTING OF PORTLAND CEMENT.

Sample No.	Temperature Fahrenheit.							
	100°	80°	60°	40°	100°	80°	60°	40°
	Initial Set in Minutes.				Set Hard in Hours.			
1	1½	4	6	13	1¼	1½	2	2½
2	3	5	6	8	1	1¼	1¾	2½
3	4	10	15	20	0½	0¾	1½	6½
*4	5	9	15	30	0½	0¾	1	6
5	6	10	14	25	1	1½	2	2½
*6	7	12	15	20	1¾	2	2¼	2½
*7	9	10	15	17	3½	6	7	12
8	10	15	35	40	0¾	1	1¼	1¾
9	11	15	20	57	3	5	6	10
10	11	13	15	30	2½	3	3½	6
11	19	32	60	120	3	6	7	15
12	15	35	70	360	3½	6	7	22

* Contain a considerable admixture of Kentish Rag.

May 6th, 1895.

WILLIAM G. PEIRCE, President, in the Chair.

STREET SUBWAYS FOR LARGE TOWNS.

By Charles Mason.

Introduction.—The importance of an improved method of underground subway construction, although an old subject for casual discussions, has, the author believes, never been brought in a practical manner before a body of Engineers. Although many reports have been prepared by Municipal Engineers, evidence given, and parliamentary powers obtained for the construction of subways for the reception of mains beneath the streets of our large towns, little has been done, and the subject is still one that should have the serious consideration of the Engineers to our public authorities, gas, water, electric light and other companies.

Necessity for Subways.—The old-fashioned method of laying underground pipes is such that a periodical inspection of the mains for ascertaining their condition or for stopping leakages, is almost impossible. Especially is this the case with our gas and electric mains, and the recent explosions in several parts of the metropolis have imposed a duty upon those having the control of our streets to devise some better system, whereby material laid under ground, of whatever nature, can be easily examined from time to time. The construction of subways is the most satisfactory and in fact the only method for laying pipes and mains so that these conditions can be complied with. The necessity for subways is also brought daily to our notice by the ruthless manner in which the street pavements are continually being disturbed in order to lay new mains, repair leakages, and for other purposes that are necessarily of almost daily occurrence. For those responsible for the maintenance of the pavements nothing can be more disheartening than, after having spent a large amount of time, energy, thought and money in designing and executing as far as possible a perfect pavement, to see the whole pulled up and practically ruined within perhaps a few days of the pavement having been laid.

Present Underground Arrangements Unsatisfactory.—In fact nothing could well be more unsatisfactory than the present system, although the author is free to admit that any remedy is attended with many difficulties unknown to the ordinary observer. It is now almost an axiom in building that no pipe must be out of sight, and any one erecting a house and burying the supply or waste pipes in brickwork or plaster, or by other means making them inaccessible, is looked upon somewhat as a "jerry builder." The same law should apply to the streets, for what is lost to the householder in case of a desired examination for an escape is also lost to the ratepayers in examining an underground main. Undetected leakages may also—and often do—exist for long periods, some one suffering thereby, as for example :—

1. The householder, in the case of a leakage from the water main percolating into his basement.
2. The water company from loss of water.
3. The gas company losing gas, as the condition of the subsoil of our streets fully proves.
4. The public generally from risks incurred in using the streets.

Interference with Street Surfaces.—Examinations for leakages are the main cause of disturbance in the pavements, these being generally made in a hap-hazard kind of way, as it is somewhat a matter of guesswork to define the exact spot requiring attention. In a recent examination in the Strand near Charing Cross, an irregular area of about 19 square yards was displaced by an Electric Light Company before discovering the leakage for which a search was being made. Had the exact spot been known, the whole could have been repaired with less than one yard superficial of the road having been disturbed. This one leakage cost at least 14*l.* to discover, apart from the cost of the actual repairs to the electric conductor. Again, in order to find a leakage from one of the water mains, no less than six trials were made, lasting over a period of more than one month, and costing the Company 25*l.* irrespective of any repairs to the main. In addition to this expense to the owners of the several mains, the pavements are irretrievably damaged, and the life of the same materially shortened. The author has no hesitation in stating that the re-paving of the Strand in 1893 would not have been necessitated for at least another year or two had it not been for the many disturbances it had been subjected to.

No Recognised System of Laying Pipes.—By the present system pipes are laid on the "first come, first served" principle: plans are submitted to the local authorities showing the proposed route, and duly approved. When the ground is opened, however, it is often found that other pipes are in the way, consequently detours have to be made; and the author has known instances in a street containing many pipes, where mains have to be "looped" from point to point. Dead or disused pipes also exist in the streets in many cases, which should be taken out, as a foreign company may not interfere with them, consequently they become as much a block underground as the live pipes; they moreover serve as conductors for gas in case of explosions.

Acts of Parliament.—Powers to construct subways are now generally included in local acts for street improvements, special clauses being introduced for enforcing their use by those for whom they are constructed. It was found in the case of the Holborn Viaduct and the Southwark Street subways that the first acts did not contain this proviso.

Companies' Present Powers.—The powers granted to the various companies by Parliament give them authority to—

1. Break up and lay mains under streets.
2. Open up for repairs; and for
3. Constructing distributing boxes, &c., &c.

All subject to due notice (except in case of emergency) being given to the authorities.

Bye-laws.—Under the London County Council Subways Act, 1893, the council is empowered to make bye-laws for the regulation of those using the subways. These bye-laws contain stipulations as to access, time of entering, fees for entering, rental, &c., which are not altogether favourably received by the companies. It is, however, absolutely necessary to have regulations, and any one control over different interests is generally looked upon as arbitrary.

Municipalities lose Control of the Streets.—It will be seen that under existing arrangements the control of the London streets is far from being, as is generally supposed, entirely in the hands of the local authority; if the various companies were under one control, the local authorities would certainly be in a better position to cope with the many difficulties they now experience.

Early Subways.—The earliest subways constructed in London are those in Southwark Street and Garrick Street, which were made about the year 1862. The first provincial town to adopt the principle was Nottingham, one having been constructed there in Victoria Street in 1863, from the designs of the late Mr. Marriot O. Tarbotton, a former member of this society. The granite pavement in this street was not interfered with in any way for the first 25 years of the subway's existence. This fact speaks for itself as to the value of an underground construction. Subways have also been constructed in connection with most of the metropolitan improvements, as in the case of the Holborn Viaduct, Thames Embankment, Charing Cross Road, &c., and the principle is now being generally adopted by the County Council in all their street improvements.

London Subways.—The London subways are, however, in the author's opinion, too small, and should be made to embrace the greater part of the width of the street. The Charing Cross Road subway (Fig. 1) illustrates the author's meaning. This subway is 11 feet 6 inches wide by 6 feet 6 inches high, with laterals or sideways placed from 30 to 60 feet apart, and will not conveniently hold the number of pipes that should be laid therein. An insufficient number of laterals or sideways are also provided, many of the supply mains having to pass out of a lateral and then down the footway to their destination. Difficulty is also experienced in crossing the subway with branches from the main pipes, as in the case of a gas main being placed on one side of the subway where the branch for supplying the opposite side of the street has to be taken over the subway immediately underneath the soffit of the arch, thus obstructing the passage way, besides tending to form in the bends of the pipes accumulations of water, &c. The provision of longitudinal sideways for service supplies, as suggested in the author's proposals (Fig. 3), is a means of preventing this crossing of the subway by branch pipes.

Provincial Subways.—Through the courtesy of Mr. Arthur Brown, M. Inst. C.E., the Borough Engineer of Nottingham, the author is able to show (Fig. 2) details of the subways constructed in that town in 1887, at the time the author was the assistant engineer to the corporation. These subways are similar in general arrangement to those in the metropolis, but vary in size and have more laterals or sideways. In this case, moreover, vaults were constructed beneath the footway, and being the property of the corporation, were leased to adjoining owners, thus giving some return to the corporation for the outlay. The subway is 10 feet wide by 6 feet 6 inches high, and is provided with ventilation by means of open gratings overhead. The sideways or laterals are 4 feet high by 3 feet 6 inches wide, spaced 40 feet apart, and so arranged as to carry the pipes and drains to and from two properties. The vaults under the footways are 9 feet 3 inches wide by 7 feet high, and are readily leased to adjoining owners at a rental equal to 5 per cent. on the cost of their construction.

The subways adopted in the metropolis as well as those in Nottingham, although being a step in the right direction, do not, in the author's opinion, meet the case as fully as is necessary. Considerable difficulty is experienced by the several companies possessing pipes therein in connecting from the subway to the premises to be supplied, and it is found that this construction, although minimising to a very great extent the breaking up of the street surfaces, does not, especially in London, entirely obviate it.

Difficulties of Construction.—The author is fully alive to the difficulties of designing a subway that shall be satisfactory to all parties concerned, and he is of opinion, as before stated, that most of the subways already constructed are open to several objections.

The Author's Proposals.—The main points for consideration in designing a subway are :—

1. The number and size of mains likely to be laid therein (present and future).
2. Ample space for workmen.
3. Pipes to be so placed as to allow facilities for repairs, connections, &c.
4. Provision for sewer inspection and ventilation.
5. Light and ventilation to the subway.
6. Service pipes not to cross the subway.
7. Gas and water pipes to be laid with a fall.
8. Overhead construction to be watertight.
9. Provision for street gullies, lamps, fire-hydrants and water posts.

To meet these requirements the author has designed a subway (Fig. 3) suitable for the busiest thoroughfares of large towns. The diagram shows a subway adapted for a street 50 feet wide. The principle is a triple subway, having a central avenue for the trunk mains and sewer, and subsidiary or supply subways on either side for the smaller pipes from which are taken the house connections. The central avenue is 10 feet wide by 6 feet 3 inches high, with a segmental arch over; the subsidiary subways being 6 feet wide by 6 feet high. The whole is constructed in cement concrete with brick arches and glazed brick facings throughout. Vaults are provided beneath the footways, which should be the property of the authority, and leased to adjoining occupiers. The author makes a strong point of this, as in many cases the fact of the vault construction being private property prevents the public authority from making satisfactory repairs to the footpath. A tramway is provided in the central subway for carrying materials. The public sewer is placed beneath, with manholes at stated intervals; the house drains passing from the inspection areas in the vaults to the sewer in the ordinary manner. Gulleys are provided in the floor of the subway to receive the washings of same, and in case the water mains require emptying.

The street gullies are placed over the spandrels formed by the vault construction, piers being built for encasing them where necessary. The outlets from these gullies are carried down through the subway construction into the sewer, and are also carried up to the footway pavement for inspection and cleansing. An asphalt damp course is laid over the arching, outlets for the drainage thereof being provided at intervals in the springing, and connected therefrom to the sewer below.

The sideways are approached from the central way by arched openings 4 feet wide in the division walls. The whole construction is covered with concrete floated to the contour of the roadway to receive the paving. Light and ventilation are procured by means of overhead gratings opening into the roadway, and special openings for this purpose are provided at regular intervals, being adapted as street refuges. The sewers must not be ventilated into the subway; special means are provided for this by pipes taken from the sewer and carried up the adjoining buildings, or connected with the external air independently of the subway.

Street lamps and water posts are fixed on the footways over the spandrels of horizontal arches, stoneware pipes being built in from the bases of same to the subsidiary subways for the reception of the gas and water supplies, which can be drawn through these pipes when repairs or renovations are required. The large trunk mains rest upon sleeper walls, and the smaller ones are carried upon brackets built into the wall or attached to the overhead arching. These latter carry the telegraph, telephone and lighter wires. All the pipes are placed at a distance from the walls, so as to allow for junctions, valves and connections; special passages or chases about 12 inches by 9 inches are left through the vault walls for passing through the services. These passages can be closed by suitable blocks or other means at each end.

Street fire hydrants must be placed in position similarly to the lamp columns, it being essential for them to be readily accessible from the road surfaces. Should it be necessary and desirable to construct electric transformer chambers for the high tension cables, these can be placed in arched openings in the division walls of the subway; but in the author's opinion all transformers should be entirely upon the property of the company owning the same. Special entrances are to be constructed for the reception of pipes and other materials, and these can be arranged where side streets and courts abut upon the main street in which the subway is placed.

Cost of Construction.—The author does not advocate the principle of constructing subways in all existing streets, as he is well aware that it would be almost an impossibility for financial reasons, as well as from interfering with the central traffic during the subway construction. He, however, is strongly of opinion that this form of subway, or a modification thereof, should be constructed in all new streets and in cases of street improvements, and, in fact, wherever a suitable opportunity for their introduction arises. The author estimates the cost of construction, exclusive of the street pavement and sewer, at 80*l.* per yard run of street, and he submits the following estimate of expenditure and receipts for the working thereof for a street six hundred yards in length:—

Cost of subways: 600 yards at 80*l.* = 48,000*l.*

This amount could be borrowed at 3 per cent. for (say) 50 years, the annual expenses will therefore be:—

	£	*s.*	*d.*
Expenditure—			
48,000*l.* at 3 per cent. for 50 years' annual repayment of principal and interest	1,694	8	0
Annual repairs, and supervision, say 1½ per cent. ..	720	0	0
	£2,414	8	0
Receipts—			
300 vaults, spaced four yards apart (c to c) on either side of street, at 7*l.* 10*s.*	2,250	0	0
Saving in cost of repaving—original costing 3000*l.*: the life of same increased by the subway from four to five years	150	0	0
Ditto in sewer examinations and gully connections	20	0	0
* Annual rentals for mains in subway, say	200	0	0
	£2,620	0	0
Estimated annual saving	£205	12	0

This estimate shows a balance in favour of subways, mainly on account of the vault rentals. Exception may be taken to this, but the author maintains that the whole of the street and subsoil thereof should be vested in the public authority, and in all applications to Parliament for new streets a clause to this effect should be embodied. The cost of the subway is almost prohibitively high, but the author brings the figures as well as the facts forward in order to show the chief difficulty experienced by local authorities in subway adoption, viz. that of cost. However, it is impossible to place on the credit side in actual figures the enormous saving which would no doubt accrue were the streets to be kept free from obstructions necessitated by the present disturbance of the pavements. Accidents occur almost daily in some parts of the metropolis from this cause, which never come to the knowledge of the local authorities, and there is no doubt that many hundreds of pounds are annually lost in horse-flesh, rolling stock, and through personal accidents to those using our streets for the ordinary business of life.

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* The actual cost of street disturbance for five years in one of the London streets (600 yards in length) amounted to a yearly sum of 243*l.*

Subways in Old Streets.—Another serious difficulty occurs in adopting subways in old streets, viz. the question of taking up existing mains and relaying them in the subway; the companies would no doubt object to having their systems interfered with at their own expense, and a considerable additional outlay would be incurred by the local authority were the cost of this to be placed on them. The single subways, as in Nottingham, cost from 35*l.* per yard lineal, and these are very well adapted for provincial towns where the underground system of pipes is not so extensive as in London, but the same difficulties arise from the fact of the subways not being in duplicate so as to dispense with the necessity for crossing the subway with the supplies.

The London County Council have a scale of charges fixed at a lump sum per subway for each size of pipes, in addition to which fees are taken for time in laying or repairing pipes, and for opening and closing the subway. The author recommends abolishing all fees and making the annual rentals inclusive, thereby reducing the number of objections raised by the companies to the present system.

It should further be mentioned that subways will effect a considerable saving in the cost of roadway maintenance and repairs to the pipes in cases of severe frost, when the water in the mains becomes frozen (as in the past winter), and subsequent leakages occur. The temperature of the Nottingham subways was found to have a range of only 5° against a range of 34°·2 in the outside air, the lowest reading in the subway during the winter of 1890–91 being 40·7 as against 19°·2 outside, the highest in the subway being 45°·8, and the highest outside 53°·4, thus proving immunity from risks of frozen pipes.

Inspection and Supervision.—A permanent inspector should be appointed for the supervision of all subways. Such inspector to be the servant of the local authority. His duty would be to see that everything was in order, and that none but those possessing proper passes were admitted. Those renting the subway should be at liberty to enter as and when they please, without having to waste time in procuring keys and giving notices as at present.

Generally.—A strong point in favour of subways is that of wear through rust in the iron pipes when laid in the ground, and which frequently becomes a serious question. Iron pipes in subways, when properly coated, should have almost an everlasting life. The author's experience having chiefly been in built-up areas, it must not be inferred that he advocates the construction of expensive subways in suburban districts; but only where the traffic is so enormous and the interests of adjoining owners so great, should the principle be adopted. But it is (and this is a most serious objection to their construction) necessary in busy thoroughfares to stop all traffic and interfere materially with the supplies of gas, water, electricity, &c., during their construction. The author has accepted, without comment, the principle of the municipalities owning the subways, as it would be unwise for each company to construct its own subway, besides being prohibitive on account of the cost, which would be proportionately greater, and fall directly on the companies. The whole should be constructed by the municipality, under their own control, maintained by them and leased to the companies. This is not the time or place to discuss the complex problem of municipalising the public companies, but there is no doubt such a course, from a municipal point of view, would cause less inconvenience to the public using the streets.

Conclusion.—In conclusion, the author feels that he has introduced a very controversial subject, but one the importance of which is universally recognised; the form of subway proposed can only be adopted in central districts of large towns having valuable frontages; but some cheaper form of the triple system could well be (and should be) introduced in those districts unable to bear so heavy a cost as the subway devised by the author. The initial difficulty is the question of cost, and the best way to overcome this, is for the local authority to own the subsoil of the roads, and lease the vaults constructed therein.

DISCUSSION.

The PRESIDENT said that, being a water engineer, he was frequently brought into contact with the surveyor's department, and he found that scarcely a week passed without some accident occurring to the water pipes; and the road after being thoroughly and properly made had to be broken again. After the road had been broken up it never had the same appearance that it had at first. He had that day measured a road at Richmond, the width of which was 14 feet. In it were four London water mains passing from Hampton. There were two 30-inch mains, and two 21-inch mains. The main of the Richmond Waterworks was 14 inches in diameter, and there was a river water main of 6 inches. That made six water mains under the roadway. Then there was a 3-inch gas main, a telephone main, and a pipe from the Richmond Water Company's reservoir. Before he could put the latter down he was obliged to shift the gas main, and the pipe was only 8 inches below the surface of the road. When it was necessary to repair either of the mains, the operation was a most difficult one, for they were laid one on the top of the other. These pipes passed through the main streets, except one large main, which was carried down a by-street for convenience. One of the largest was only 5 inches under ground, so that there was some difficulty in setting the granite pitching at the crossings. There was a possibility of there being a new street made through the town at Richmond, and there was not the slightest doubt that, if the Corporation would go to the expense of making a subway, it would be a great saving in the end. But to alter the conditions of such a road as he had described would be a very difficult operation. The paper was one which ought to be brought before the governing bodies. His opinion was that when corporations were made acquainted with the facilities which could be obtained for the cost of, say, 80*l.* a yard through the principal streets, they would see that it would be a great advantage, not only to the residents, but to all concerned, to adopt subways. He would propose a cordial vote of thanks to Mr. Mason for his valuable paper.

The vote of thanks was carried by acclamation.

Mr. A. T. WALMISLEY said the subject was not only a controversial one, as the author had said, but it was one of great public importance and interest. If by any means they could prevent the surface of streets and main roads being perpetually broken up, there would be the prevention not only of a great nuisance, but also of a great impediment to business. The author had given a comparison of the temperatures in the Nottingham subway. That, he thought, was one of the most important subjects in the paper, because it might be imagined that, in such a case, the coldness of the air would be one of the greatest objections that could be raised against the subway. There was nothing so dangerous for a water pipe as to have cold air surrounding it, and the same cause would also lead to a deposit of naphthaline in gas pipes; but it seemed, from the experience which had been gained at Nottingham, that the temperature of a subway was not detrimental in either of those respects. The past winter had been very trying to water-mains, and he should have liked the author to have given some statistics with regard to the recent subway temperatures. He (Mr. Walmisley) had under his care, as the engineer of Dover Harbour, a water main running down the Admiralty Pier at Dover in a very exposed position. That main was laid by the Board of Trade many years ago in a trough about 14 inches wide, and covered in with York stone about 2 feet below the masonry sets, which formed the platform of the pier. Nothing happened to that main until last winter, when it broke in several places, and had to be replaced. He believed that the cold air in the trough around the main was the cause of the fracture, and consequently he intended to obviate the recurrence of such an accident by packing it with fine beach and filling up the trough, so that by easy removal of such beach, the men would be able to get at the main at any time. He did not think the question of cost was to be cavilled at. If a subway would prevent the nuisance to the inhabitants of constantly having the road up, the cost was one which ought to be incurred if it was a reasonable figure. With reference to transformers being placed on the property of the company in the subway, he agreed with the author; but the author was no doubt aware that some municipalities owned the electric mains themselves, and they could place them in the subway, without interference with any rights.

Mr. Ernest Collins said that the subject of the paper was one with which he had himself intended to deal; and with that object in view he had for some time been collecting data, some of which he trusted might be of use in strengthening the discussion. The company with which he was connected, namely, the New River Company, had, he believed, in their district the longest length of subways of any company or corporation in the United Kingdom. It amounted altogether to 4½ miles. They also had about 7½ miles of pipes laid in these subways varying from 24 inches to 3 inches in diameter. The question as to the necessity for the construction of subways, was one which he believed most of those present would be prepared to admit. No opportunity should be missed of constructing subways where new street improvements were in progress. The subways already in existence in that portion of the district served by the New River Company which was under the jurisdiction of the City Commissioners of Sewers, were constructed by the late Colonel Haywood, and he believed they were designed upon the very best possible system. They were laid out with a great amount of common sense. They were made of such a size that they would contain all the pipes that were required. The City subways had tramways laid from one end to the other, and access to the pipes was easily obtained.

The subways constructed by the Metropolitan Board of Works were laid out under the supervision of Sir Joseph Bazalgette, who adopted one section throughout. It was, he (Mr. Collins) believed, 12 feet wide and 8 feet high. Those subways answered very well, and they were properly ventilated, but in some cases, as, for example, in Queen Victoria Street, they were so full of pipes, gas mains, hydraulic mains, and electric wires, that it was almost impossible to get into them. The Queen Victoria Street subway was in a very slovenly condition, and it was not paved. A person walking through it was covered to his ankles in dust and dirt. Should any accident occur to the mains, the cost of repairing, independently of the time occupied, would be something fabulous. Up to the present nothing had happened, but if anything did occur, the top of the street would have to be opened, in order that the workmen might get at the pipes in the subway. The last subway constructed was in Rosebery Avenue, which was the first street improvement laid out by the present County Council. He believed that great objections could be taken as to the way in which that work was carried out, but he did not say that it was altogether the fault of the County Council. They had a length of subway which started from St. John Street Road, near the Angel, and ran for a distance of 698 yards, the section being 12 feet by 8 feet. The subway, for the greater portion of its length, now contained a 7-inch pipe, a 6-inch hydraulic pipe, a small gas main, and a few electric wires. He did not think that it was likely that any other pipe would be put into it. This subway was unnecessarily large for what was at present required, or was likely to be required in the future. At 678 yards the subway reached Farringdon Road, where seven streets converged, with an immense amount of traffic from the new Post Office, and there came to an abrupt termination. Thus the subway terminated at a place where it was most required, and no subway existed for a distance of 161 yards, where the Warner Street Viaduct commenced, and the pipes were dipped down to a depth of 14 feet into another subway of a different section. That subway continued for a distance of 43 yards, terminating at Warner Street, where the pipes left the subway and were dipped under Warner Street, rising again on the other side into another subway, continuing for a distance of about 99 yards. Then directly they came again to where all the traffic converged from five different directions by the Holborn Town Hall, where there was no subway at all. That state of things might have been entirely prevented had the authorities consulted those who would in the future use the subways, as to what might be required.

He had often been asked whether it was more expensive to lay pipes in a subway than in a road. That was a somewhat difficult question to answer. Wherever they had had to lay pipes in subways, they had always been on the alert, and they had laid their pipes before anybody else got there, and they had got them in for about the same price as it would have cost to lay them in the roadway. In laying pipes in a subway many things had to be considered. When pipes were laid in the road, a trench was dug. That involved a certain amount of expense, but the trolley brought the pipes to the exact locality where they were required; whereas when a subway was used the pipes had to be dropped down at the entrance, and men had to be employed to lift them off the van and put them on the rollers, and planks to carry them 100 or 200 yards underground. The contractor could not see what the men were doing, and engineers knew what men were when they were not looked after. Then again, there were certain restrictions. The men must not use molten lead or a naked light, but had to employ a safety lamp. The contractor had to build brick piers, or perhaps provide iron brackets to carry the piping. When all these matters were taken into consideration, there was not much difference in the cost of laying a pipe in a subway and laying it in the roadway. He believed it would cost more to lay a pipe in a subway like that in Queen Victoria Street than to lay it in the road.

The author might have said a little more about ventilation. It was one of the most important things in connection with subways. In fact, ventilation was the whole secret of the success or non-success of a subway. He believed that, although the Queen Victoria Street subway was in many other ways defective, it was, so far as ventilation was concerned, one of the best constructed subways, the reason being that it was built on an incline from the Embankment at Blackfriars to the Mansion House, so there was a continual draught flowing through from bottom to top. As long as that was the case, there was not, he thought, any danger of explosion. To show the difference of opinion which existed about ventilation, he might point out that in the County Council regulations no company using a subway was allowed to use a naked light, or to melt lead, and they were not allowed to take molten lead into the subways. In the City of London subways it was quite different. Colonel Haywood had said to him, "I am not afraid of ventilation; I know that that is all right. You may use anything you like, and not only that, but I will light the subway up for you." He had open gaslights from one end to the other. There was rather a difference of opinion upon that matter. His experience of subways was that, up to the present, they had not had any bad accident at all, and no breakage. Of course, a breakage might come some day, and when it did it would be a very serious matter, but he thought that one of the great benefits which they would derive from subways was that the pipes would be seen. He believed that the breakages which they had in their mains underground were very often due to a small beginning. A joint began to drip, and no account was taken of it. Being underground, the drip did not show, and then it became bigger and bigger, and it gradually washed away the ground all round the pipe, and eventually there came a collapse. The pipes laid in the subways of which he had spoken were examined every day, and the smallest drip was immediately stopped. That, he believed, was the reason why they had not had any very bad bursts in their subways.

Mr. A. W. Ackermann asked whether the estimate of 80*l.* referred to the ideal section on the wall.

Mr. Mason said that it did.

Mr. Ackermann said that he did not see any provision on that section for electric trams or wire-rope trams. He remembered that when the first subways were laid in London there was a great deal of opposition, and much was said about the danger of explosions; he had not heard of any explosions, and would like to hear the author's experience. As to the quantity of pipes shown, his own experience was that in most works engineers made some provision for the future growth, but the future always seemed to beat the provision, that was to say, the accommodation generally proved inadequate. He fancied that even the liberal amount of space shown by the author would be insufficient for the future. It was very important that there should be ample light, and that the subways should be well ventilated. Of course a street of 50 feet was rather narrow, compared to those of continental towns. It would be interesting if the author could add the cost of some of the subways which had been made at Nottingham and other places, especially as, in the future, subways would be more used. In a town with which he was connected, he had to take up widths of 5 or 6 feet of rock for each house connection. Had a good subway existed in the rock the connection-holes could have been bored through at right angles to the subway at much less cost.

Mr. J. Patten Barber said he happened to be one of those unfortunate engineers who had a great deal of trouble with reference to the opening of roads. The difficulties of opening the roads were, of course, considerably increased by the outcry of the ratepayers against the companies. The ratepayers seemed to imagine that the companies wilfully damaged the roads. If subways could be adopted in the principal thoroughfares, engineers would be saved a great deal of anxiety. But he feared that, unless the question of subways was dealt with in a more liberal and conciliatory spirit by the local authorities, those authorities and the public companies would always be in disagreement as to the use of the subways. Subways, when constructed, ought not to be regarded as the sole property of the local authorities, at whose expense they were constructed. It must be remembered that the public companies had now Parliamentary rights to place their mains in the public ways, and the attempt to induce public companies to use subways must not be made in a high-handed manner. The existing rights of the companies must be recognised. Mr. Mason's principal objection with regard to the construction of the Nottingham subway seemed to be the difficulty experienced in crossing from one side to the other by the service-pipes of the houses; but he believed that it was now the practice in large and important thoroughfares for gas, water, and electric lighting companies to lay the main along each side of the street, so as to shorten the service-pipes to the houses. If that plan was adopted in the Nottingham case, and the service-mains were laid on each side for gas and water, there would be no necessity for the service-pipes to cross the subway.

The section which Mr. Mason had designed (Fig. 3) was a good one, but there were one or two points in which it might be improved. In the first instance, he presumed that the cost of the vaults was included in the 80*l.* a yard run; 7*l.* 10*s.* seemed to be rather a large annual sum to charge for a vault which, apparently, measured only about 8 feet square. The inspection chamber for the house-drain was situated in the vault, and if the vault was used for the storage of coal, or other material, it would be impossible to obtain access to the drain and the intercepting trap, without moving the contents of the vault. He would suggest that the intercepting trap should be placed nearer to the sewer, and that, instead of having a chamber, there should be a vertical shaft brought up into the main subway, so that any deposit might be removed from the intercepting trap through that shaft. Any stoppage in the house-drain itself might be removed by passing rods from the chamber at the rear of the house, right through the drain to the intercepting trap, and the matter causing the stoppage could be removed through the vertical shaft referred to. That would save the cost of constructing the chamber in the vault, and would also render the intercepting trap more accessible than it would be if placed as shown in Mr. Mason's design. He thought that there would be some difficulty in removing a stoppage from the drain leading from the street gully. The usual plan was to make the drain perfectly straight from the outlet of the gully to the sewer. As shown on the section it followed rather a tortuous route. He thought that Mr. Mason had hardly done himself justice in speaking of the cost of constructing a subway. He thought he might fairly reduce the cost by taking credit for the reduction in the cost of laying the house-drain. He could quite understand that Mr. Mason did not want to put the matter in a too favourable light. There would also be some reduction if the inspection chambers were removed, and a vertical shaft brought into the main subway.

An objection had been raised to the conditions imposed by the authorities who made the subways upon the persons who used them. The objection seemed to be very reasonable, for, from what he had seen of the bye-laws, the local authorities seemed to ignore altogether the rights of the companies for whom the subways were made. He thought that the companies ought to have perfectly free access at all times for the purpose of inspection and repair. The objections with regard to the use of lights might be very easily got rid of by the use of the electric light. A short time ago he tried some electric lamps made for the use of sewer men, and they were very successful. He believed that there would be very much less danger of the joints in the mains being injured by variation of the temperature in subways than in the ground.

Mr. A. A. **Gill** said that one point which had not received attention in the discussion was the enormous practical difficulty in dealing with the mains in existing streets during the making of a subway in those streets. He had in his mind the instance of the Fulham Road, which ran some two or three miles through his district. The road was a comparatively narrow one, being in places only 28 feet wide or less, between the kerbs. There were six or seven lines of mains, exclusive of gas mains and electric culverts and other mains. His company had two 24-inch mains, and two 12-inch, besides smaller ones. He observed from the section that Mr. Mason had only allowed room down the centre avenue for one trunk main. He thought that most water engineers would have a very great objection to a single main. A burst under such circumstances would be a very serious matter. When the London Subway Bill was introduced into Parliament some years ago, he went into the matter in detail, and he estimated that a subway in the Fulham Road would cost about 40*l.* a yard, if it was made to occupy the entire width between the kerbs, but in that case the sewer would certainly have to be lowered. Whether the gradients would admit of its being lowered, he was unable to say. The sewer was certainly unusually shallow. He thought the side avenues for the smaller pipes in Mr. Mason's design constituted a very great improvement. It would prevent the crossing of branch pipes, which would, of course, interfere to a great extent with the hanging of electric and other wires from the roof.

The construction of subways would never overcome the difficulty of stopping the traffic for the repaving of the streets, which was, perhaps, the greatest cause of inconvenience and loss of trade to shopkeepers. As to the Queen Victoria Street subway, he thought that any one who had been in it would fully bear out Mr. Collins's remarks as to the impossibility of repairing the mains there.

Mr. W. N. Blair said he had hoped to hear the views of gas engineers, because it was in reference to gas mains that one of the principal hindrances to the adoption of subways would arise. The danger of gas accumulating in underground cavities was well known. He might refer to the accidents which had happened through escaped gas being fired by the electric current. Two such accidents had occurred in St. Pancras, and others elsewhere. Had the accumulation of gas been greater than it was in those cases, the damage would have been very much more considerable. The chambers and culverts where the accidents had occurred were only about 2 feet by 1 foot 3 inches or 1 foot 6 inches, but the force had been sufficient to blow up the covering of the culverts and the paving of the footway. The effect in a large subway would be very serious. He thought there would be a difficulty in persuading the companies to make use of the subways. The statutory rights of the companies to use the streets must be recognised, and local authorities had no right to require the companies to use the subways. Personally he was in favour of the construction of subways, but it was just as well to look at the objections, and to recognise the dangers. Another objection was that which would arise to the security of the public if free access were given to the subways to the servants of the companies having pipes or wires therein. Bad characters might make use of the subways either for obtaining access to premises for purposes of robbery, or for producing some great public catastrophe, such as an explosion. It would be easy to personate a company's servant, but difficult to detect the offender. He thought the plan which Mr. Mason had submitted was an improvement upon the Nottingham plan. He was afraid that the cost of making the subways would be almost fatal to their introduction. The expenditure of 80*l.* per lineal yard would involve the borrowing of such an immense amount of capital that the ratepayers would not submit to it. The construction of subways would only be practicable in the case of an entirely new street, and further, could only be adopted with the sanction of Parliament. In many streets in London the introduction of subways was quite out of the question. Mr. Mason did not give the proportion of the cost of the subways proper to the vaults. In Nottingham the cost of the vaults was about 20*l.* each. It was a little difficult to see how the total of 80*l.* was made up. A rental of 7*l.* 10*s.* for the vault would be about 33 per cent. of the cost, taking the cost at Nottingham as the example. The property owners alongside could not be compelled to take the vaults into their occupation. They would only do so to oblige the local authorities, and they would require a price which would be convenient to themselves.

A question which had not been mentioned was that the subsoil of the road did not belong to the local authorities. It belonged to them only so far as might be necessary for the purpose of constructing the roadway and the sewers. The owners of the property on each side were the owners of the soil, and they had a right to construct anything attached to their premises in the soil so long as it did not interfere with the use of the surface of the road by the local authorities. A property owner might claim the right to construct a vault in his own way, and prevent the local authority from absorbing part of his property. The practical difficulty of repairing mains and subways which had been mentioned by Mr. Collins was one which would influence the gas companies in deciding whether they would adopt subways or not.

Mr. W. H. Bale said there was very great difficulty in connection with gas mains in finding out leaks when the mains were laid in the subsoil. He thought that the placing of the mains in a subway, as shown in the diagrams, would be a very great improvement in that respect, especially if the inspection of the mains was regularly undertaken, say, for instance, daily. The inspector would be able to detect and remedy at once any leak that might be found, which not only means safety, but, by prompt action, a great saving of gas.

Mr. Blair said that he was very pleased to hear the opinion which had just been expressed by a gas engineer.

Mr. W. Schönheyder said that he agreed with the author in almost everything which he had written in his paper, and he could fully see the enormous advantages which would be derived from subways. But there was one great difficulty about the matter, and it seemed to him to be almost insuperable, and that was that towns, and especially large towns, invariably grew from small beginnings, and in nine cases out of ten it was perfectly impossible to tell beforehand which street would become important, and to say what size its subways ought to be in order to contain, with reasonable facility, the number of mains which would be put in. If new streets were cut through an old town, there would only be one here and there, and although, in such cases, subways might be made, and the number and size of pipes might be fairly estimated, it was, as Mr. Collins had very truly said, a great drawback that there were only short lengths of subway, and that throughout the larger part of the town things had to go on in the old way. He very much liked Mr. Mason's design, and he regarded the duplicated service—that was, a service on each side—as a great advantage. He did not know what the upper main shown on the diagram was, unless it was a hydraulic main or something of that kind. He thought that Mr. Mason had hardly given sufficient prominence to the advantage of the subways in his estimate. The largest sums which he had taken credit for arose from the letting out of the vaults. He (Mr. Schönheyder) would not have thought that much would be derived from that source, but he did not see any estimate whatever of the enormous saving to gas and water companies by avoiding leakage, which must be very great. They saw over and over again the joints of gas mains bared in order that they might be caulked up again. The amount of gas which escaped was enormous. The same with water companies. He had heard many statements of water engineers as to the quantity of water they lost through the mains alone. The subways would do away entirely with that waste, and the advantage of that would be enormous. Perhaps it was difficult to estimate the value of the material lost, but he thought that some kind of estimate might be put upon it, and something should be allowed also for the saving of the necessity of continually breaking up and remaking the streets. The enormous waste of water now occasioned by the putting up of stand-pipes in winter would also be prevented. That also ought to be taken into account in estimating the saving.

Mr. Maurice Wilson said that the author of the paper did not seem to be sanguine of laying subways to any very great extent at first, but that he expected to lay them as opportunity occurred in new roads. What did he propose to do, when he got to the end of the subway, with the gas and water mains and electric wires? The depth to which the pipes would have to be carried in the roadways to join with the pipes in the subway would be very great. It seemed to be a recognised fact that the gas and water companies could not be forced to use the subways unless they chose. If a subway occupied the whole of the space beneath a road, what would be done if one or more of these companies refused to make use of the subway for their mains?

Mr. E. Collins said that a Bill was passed two years ago by the London County Council for the regulation of subways, and in that Bill it was expressly stated that where a subway was constructed, and under the jurisdiction of the London County Council, the companies were, if called upon to do so, to remove their pipes into the subway at the expense of the Council, and that where a subway was constructed in a street a company would not be allowed, except under certain conditions, to open the street without giving to the authorities five days' notice.

He had the temperatures of the Holborn Viaduct subway taken during the late severe frost, and the lowest temperature was found to be 45 degrees, four feet above the ground.

Mr. J. W. Wilson, jun., said it appeared from the paper, with reference to the want of a recognised system of laying pipes, &c., that plans might be submitted to and approved by a local authority showing the proposed route of new mains, &c., and then, when the ground was opened, many impediments might be found which were not by any means anticipated. He hoped that in most cases the local authorities would know fairly well what arrangements existed underground, at any rate, of a comparatively modern nature, and would be careful not to approve of any addition thereto which could not be carried out. Mr. Blair had alluded to the possible danger to the public arising from unauthorised access being obtained to the subways, and from them to the adjoining houses. That certainly was an important matter to safeguard against, though he did not gather that there was necessarily direct access from the proposed subway to the vaults or basements of the houses. He might mention that in the case of Somerset House, where the registration records of the nation were kept in an extensive ramification of vaults, visitors had been refused access to them since the dynamite scare. Previously they had been allowed to go down into them in the company of an attendant. It was possible to imagine a great catastrophe being caused by mischievous persons obtaining illicit access to street subways. The public, however, might console themselves with the fact that there were already many subways in existence, and that up to the present no catastrophe had happened. Several speakers had suggested that in the future there would not be room enough in the subways for all the mains which would have to be laid. But if they did as the author proposed, and made the subway the whole width of the street, it was difficult to see how better or more commodious provision could be made for future development. The advantages which had been propounded during the evening in connection with the use of subways indicated that the author had brought forward a subject which had much more to commend it than could be said against it.

Mr. T. W. Baker said it seemed to him necessary that there should be some good inducement to the water and gas companies to lay their pipes in a subway instead of laying them in the ground. He thought the increased life of their mains would be a very considerable inducement. He suggested that it would be very useful to know the difference between the life of a main laid in a subway and the life of one laid in the soil, and that, as several gentlemen were present having an experience of this, they might give the meeting their opinion.

Mr. E. Collins said that he had not lived long enough yet to see how long a pipe would last in a subway, though he hoped he might do so. A pipe laid in the ground in good solid clay would last for ever; but a pipe laid in ashes and other bad materials had a very short life. A pipe that was laid in a subway was always open to the effects of the atmosphere; and although pipes might be coated in the way the author suggested, with Angus Smith or any other composition, the coating would peel off in consequence of the continual changes of temperature and the exposure to which the pipe was subjected. Another thing was that where pipes were in a subway there was a constant expense in cleaning and painting them. The company which he represented had all their pipes painted throughout the subways, at very considerable expense, about every three years. The painting was, however, necessary. He thought that it might be safely said that the life of a pipe in a subway was not so long as the life of a pipe in the ground.

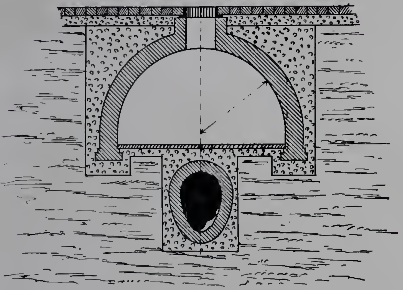
Mr. Mason, in reply, said that he was more than gratified with the discussion. The subject was one that was hedged about with difficulties. Even persons who were in favour of subways had some valid objection to them. The President had mentioned the case of a road at Richmond 14 feet wide with six water mains. That road was a strong argument in favour of subways. He was sorry that he had no statistics such as Mr. Walmisley had asked for, but Mr. Collins had favoured the meeting with information which would partially answer the question. The first cost of subways was the great drawback to them, but, as Mr. Walmisley had said, the public ought not to grumble at the expense, as there would not be the amount of interruption to business which now took place. The Holborn Viaduct Subway was practically on the principle which he (Mr. Mason) was suggesting. The Viaduct scheme embraced underground warehouses, &c., in combination with the subway. The subway proper was lighted up with gas, and naked lights were used in carrying out repairs. Mr. Ackermann had asked a question with regard to gas explosions. He (Mr. Mason) only knew of one gas explosion in a subway, and that was at Paris. It occurred fifteen or twenty years ago, and was now a matter of history. It was attended with very serious results, but was due entirely to carelessness. Since that time the gas mains of Paris had not been allowed in subways at all. Evidently the Parisians did not seem to have sufficient confidence in their pipe-joints.

Mr. Blair had referred to Nottingham, and he (Mr. Mason) ventured to say that Mr. Blair was mistaken in the cost which he had quoted. He believed that that subway cost 25*l.* a yard. He had put the London vaults at a heavy rental, because they ought to let at a higher figure than the vaults in a provincial town. It was very difficult to get information as to cost, but he believed that the subways cost in London something like from 25*l.* to 40*l.* a yard; and the French subways cost 1000 francs per metre, or about 40*l.* a yard. Mr. Barber was good enough to explain the difficulties of the municipal engineer, which, of course, were the difficulties which he (Mr. Mason) experienced. As regarded the drainage question and the idea of putting the inspection area in the subway, the idea was a very good one, and he was much obliged for it; but it was attended with the great drawback of the householder not having complete control over his own drainage system, which he ought to have, and he would not be able to have free access to the syphon. The question of fixing the street gullies was, of course, a difficult one.

With reference to cost of construction, perhaps he (the author) had not done himself justice, but he wanted to be on the safe side. Another trunk main could be very easily put in his subway. He had abstained from showing more, for the sake of keeping the drawing perfectly clear. It was true that the traffic of the streets must be stopped when the streets were repaved, but he believed that the use of subways would almost double the life of the paving. The possibility of unauthorised persons entering a subway was a very serious objection; but a similar possibility existed in the case of sewers. There were sewer manholes in the London streets, and there was nothing to prevent unauthorised persons using them for illegal purposes. When the dynamite scare prevailed ten years ago, special iron gates were put to some of the sewers in his district to keep people from passing along, thus showing that public bodies were alive to the matter.

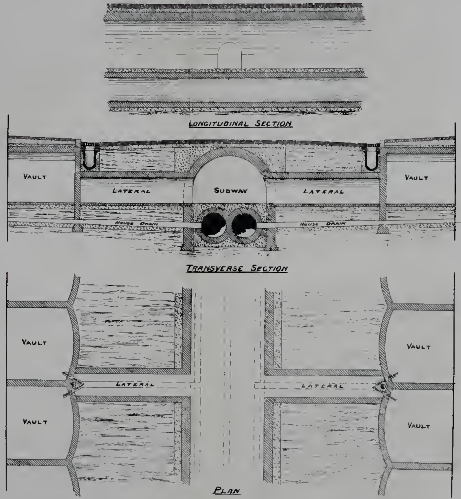
The question raised by Mr. Schönheyder as to the growth of towns was a very interesting one; and he had dealt fully with it in the draught of his paper, but withdrew the paragraph, as he felt sure the matter would crop up in the discussion. Towns grew from villages, and they must meet the case when the necessity arose, just as they had to do when it became necessary to widen streets in the centre of large towns. Mr. Wilson had said that a local authority ought to know where the gas mains and water mains were situated underground. So they ought; but they did not know, and the gas and water companies themselves even, seldom knew the exact spot where the mains were situated. It must be remembered though that those pipes were mostly laid forty or fifty years ago, when records were not kept so systematically as they were now. Having answered the main points of the discussion, he could only conclude by thanking the meeting most cordially for the reception which they had given to his paper.

FIG. 1.



TRANSVERSE SECTION.

FIG. 2.

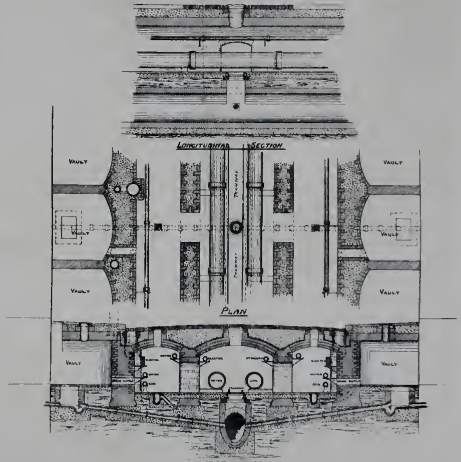


LONGITUDINAL SECTION

TRANSVERSE SECTION

PLAN

FIG. 3.



LONGITUDINAL SECTION

PLAN

TRANSVERSE SECTION

E & F.N. Spon, London, & New York

June 10th, 1895.

WILLIAM G. PEIRCE, President, in the Chair.

SAFETY APPLIANCES FOR ELEVATORS.

By Herbert W. Umney.

Although numerous papers on lifts have been read and discussed at meetings of the different learned societies and institutions, the accessories have never received other than the merest comment. The author has therefore selected the details of safety appliances as the subject of the present paper, as he considers it of the utmost importance. With the memory of the sad death by a lift accident of a member of the profession fresh in his mind, the author offers no apology for the subject of the paper; but the contents are another matter, and on this score he would crave the indulgence of the meeting.

The first weak point in hydraulic lifts, which is patent to all, is the effect of any hammer action that arises when the machine is stopped or started suddenly. This shock is in no way transmitted to the mains, as consumers are always required (where the supply enters their premises) to fix a valve which shall not only act as a stop-cock, but also as a back pressure and retaining valve, in order that any failure in the power supply will not affect the machine so as to cause it to descend. This stop-valve thus concentrates any shock on the pipes within the building, and they have to bear all the sudden increase of pressure. To relieve this stress to which the pipes would be subjected, relief valves are sometimes fixed, although, the author ventures to think, not often enough. In direct-acting and suspended lifts the danger resulting from any pipe connection breaking is infinitesimal, since diaphragms such as shown in Fig. 1 are, or should be, always placed in the joint next the cylinder, in order to regulate the speed of the lift in its ascent, and this will similarly prevent any excessive velocity of the cage when descending. The orifice in this diaphragm should always be well tapered on both sides, so that the loss of pressure may be minimised to, say, 3 per cent. To determine the diameter of a hole serving the required purpose, the author has found that the following simple and practical formula (deduced from a more elaborate one given by Mr. Henry Adams) is reliable and accurate to less than 1 per cent. of the ideal—

$$d^2 = \frac{D^2\,v}{8 \cdot 34\,m\,\sqrt{P}}$$

when d and D represent the respective diameters of the orifice and ram in inches; v the velocity of the lift in feet per second; m the multiplying power; and P the main pressure in lbs. per square inch. This formula, when the main pressure is 700 lb., works out as

$$d^2 = \frac{D^2\,v}{220\,m}.$$

When the well-known Paris accident brought about the abolition of the practice of balancing the dead weight of the ram and cage in direct-acting lifts by overhead gear, and the introduction of hydraulic balances, makers who hitherto had considered this class of lift inherently safer than those which depended upon the support of chains or ropes, did not hesitate to state that they were now absolutely safe. In water-balance lifts, however, the diaphragm to regulate the speed of ascent is of necessity put into the power cylinder, and is therefore not such a protection from risk as in the case of a simple direct-acting or suspended lift; for it is impossible to place any diaphragm in the connection between the hoisting and balancing cylinders. Hence, should the pipe (which is usually 2 inch diameter, in order that the water may oscillate freely) fail, the full weight of the ram, cage and passengers acts to force the water out of the cylinder. To provide against the obviously disastrous effects consequent on the failure of such a pipe, ram grips were made of various designs, such as Figs. 2, 3, 4 and 5. Figs. 2 and 3 show an automatic hydraulic brake, designed by Mr. Ellington to work in connection with his balance lifts, and the following is a description of the arrangement:—The lift ram R is embraced by two brake blocks A A, which, by a system of toggle levers, are connected with the piston rod B of a piston C working in a small hydraulic cylinder. The back of the piston at D communicates with the pressure water, and the front at E with the lift cylinder. If the lift cylinder should burst, and the water escape from it with a velocity sufficient to reduce the pressure within it so far that the lift descended quicker than its normal speed, the excess of pressure on the back of the piston D (not connected with the lift cylinder) will cause the piston to move forward on the brake cylinder, and so make the brake clip the ram. By connecting the two inlet pipes of the brake cylinder through a suitable valve, the brake can be controlled by hand from the lift cage, and can be conveniently used for locking the lift in any desired position, which was the object in view in designing the arrangement. The engraving shows an arrangement for use when the pressure in the mains is less than the pressure in the direct-acting cylinder; but by means of a differential ram passing out through the back cover, the apparatus can be proportioned for cases in which the pressure in the mains is higher than in the lifting cylinder. Figs. 4 and 5 represent a second design of ram grip, fitted on a low-pressure direct-acting lift, which has given very satisfactory results. The lift ram is embraced by a grip ring lined with wood and made in two pieces, hinged on a bolt, and made to clip the ram by two springs. These springs are compressed, and the ring forced open by a wedge connected with one arm of a crank lever, which is mounted in carriages and actuated by the pressure of water in the lift cylinder on the piston in the auxiliary brake chamber. When the lift is at work the pressure on the piston is sufficient to force the wedge in so as to allow the ram to pass freely up and down. If the cylinder or pipe bursts, the pressure would be decreased, and the weight of the piston would withdraw the wedge and allow the springs to tighten up the grips.

Grips, however, were not considered by Sir Frederick Bramwell sufficiently reliable for the safety of passengers travelling in direct-acting hydraulic lifts fitted with water balances, so he required that a brake valve, such as illustrated in Fig. 6, should be made and fitted on the four lifts at St. Bartholomew's Hospital in order to minimise any risk. The valve is fixed as near as possible to the lifting cylinder. Under ordinary working conditions the pressure on either side of the valve does not vary more than 20 lb., so that a light spiral spring will easily keep the valve open. Should a pipe burst, the pressure on the upper side of the valve is relieved and the valve closes, leaving only a small hole A for the water to escape through. This hole is usually about a quarter of an inch diameter, so that the sudden closing of the valve does not cause any shock, and the lift is enabled to descend gradually. Another design of valve to fulfil similar conditions, and equally applicable as a safety valve on a simple lift, working direct from the hydraulic main, is illustrated in Fig. 7. Extending upwards from the valve disc A is a spindle D which passes through a stuffing box in a cylindrical chamber E in which is a piston F carried on the spindle D. At the bottom of the cylinder is an orifice G leading to a pipe H communicating with the hydraulic main. Above the piston F, and between it and the underside of the cover of the cylinder E, is a spiral spring I coiled round the spindle D. When the stop valve which governs the water supply from the accumulator is opened, the water enters the cylinder E by the orifice G, the piston F is forced upwards, compressing the spring I, and the valve A is raised to permit the flow of water from the working valves to the ram. In event of failure in the pressure of water through the fracture of the main pressure pipe or other cause, the piston F descends, and the check valve A is immediately forced down on to its seat by the action of the spring I, the water returning from the ram is prevented from escaping, and acting above the valve, keeps it firmly closed. Some idea of the effectiveness of such a valve may be obtained by a consideration of the speed at which it will allow the lift to fall compared with the rapid descent of Lloyd's lift when the recent accident occurred. The pressure on the water in the cylinder, due to the weight of the ram, &c., was about 300 lb. per square inch, which is equal to a head of 702 feet. The velocity of the water due to such a head equals 212 feet per second, so that the quantity of water flowing out of the cylinder when the connection broke was 67 cubic feet per minute. This volume of water would require a 4-inch ram of 768 feet in length to displace it, and this represents the speed per minute at which the cage fell. Had such a brake-valve been used, the cage would have descended only at one twenty-fifth of the speed. Perfect safety would have been equally well attained, and the lift would have descended at the ordinary speed—namely, 120 feet per minute—if a diaphragm had been placed next the cylinder to regulate the speed of its ascent. The diameter of the orifice in the diaphragm, as calculated by the practical formula already given, would have been ·38 inches in diameter; that is, its area would have been about one-tenth of that of the pipe. The pipe which broke in this case was of a smaller size than that usually joining the lift and balance cylinders together, otherwise the speed would have been almost three times as great as that at which the cage actually fell, or nearly sixteen times the normal speed.

P = pressure of water in lb. per square inch .. .. .. = 300
H = Head of water in feet .. .. = 702
V = velocity of water in feet per second = $\sqrt{2\,g\,H}$ .. .. = 212
Q = quantity of water in cubic feet per minute escaping = 60 V A C
A = Area of pipe in square feet = $\frac{\cdot 7854\,d^2}{144}$ .. .. = $\frac{1\cdot 227}{144}$
C = coefficient of contraction of A .. .. = $\frac{1}{\sqrt{2\cdot 618 - 1\cdot 618\,\frac{d^2}{D^2}}}$
d = diameter of pipe in inches.. .. .. = 1·25
D = diameter of cylinder in inches .. .. = 6

$$\left.\begin{array}{l}\frac{1}{C} = \sqrt{2\cdot618 - 1\cdot618 \times \frac{1\cdot25^2}{6^2}} = 1\cdot596. \quad \therefore\ C = \cdot6265 \\ \text{Or,} \\ = \sqrt{2\cdot618 - 1\cdot618 \times \frac{\cdot25^2}{6^2}} = 1\cdot616. \quad \therefore\ C = \cdot6187\end{array}\right\}\ \text{(say)}\ \cdot62$$

$$Q = 60\,V\,A\,C = 60 \times 212 \times \frac{1\cdot227}{144} \times \cdot62 = 67 \text{ cubic feet per minute.}$$

$$\text{Rate of descent of 4-inch ram when pipe broke} = \frac{67 \times 1728}{12\cdot56 \times 12}$$
$$= 767\cdot9 \text{ feet per minute.}$$

$$\text{Maximum rate of descent of ram with brake valve} = \frac{767\cdot9 \times \cdot25^2}{1\cdot25^2}$$
$$= 30\cdot7 \text{ feet per minute.}$$

Having referred to diaphragms as a safeguard from pipe failures, the author will next direct attention to gear fitted on cages so as to arrest their motion when the hauling-chain or ropes fail. A design of one of the earlier arrangements is seen in Fig. 8 as applied to a goods lift cage. The cage is made with a strong angle-iron frame suspended from two flat plates by bars and tie rods in order to ensure rigidity. In the centre between these plates, to form a means of suspension, a flat eye-rod is passed and held on the underside by a spring and nut. On either side of the cross bars are shafts, fitted at both ends with serrated cams, and at the centre levers are keyed. Each of these levers is connected by a pair of links to the eye-bolt, so that when the cage is suspended the spring is deflected and the levers raised, so as to free the cams from the guides between which the lift runs. When the hauling chain breaks, the force of the spring rapidly pulls down the eye-bar and the cams grip the tee-irons, which, in this case, serve as guides.

A modification of this arrangement is seen in Fig. 9, where, instead of cams to grip the runners, spikes are forced out into the guides. The boxes marked A contain powerful spiral springs which bring the arms B into action as soon as the lifting ropes break, by forcing down the cross-head C, which extends the arms so that their chisel points enter the wood guides, and the cage remains suspended by the angle brackets D which are securely fixed to the top of the cage. With these gears, however, it is necessary that the guide bars should be of a very rigid construction to resist the thrust of the arms. Safety gear is now hardly ever fixed on the top of cages, because it is then necessary to construct a far heavier frame than would be required to carry the load, lest, under the dynamic stress resulting from the motion of the lift being arrested by the safety gear, the bottom of the cage should fall out, as it did in one instance which came directly under the author's notice. The exceptions to this form of construction are few, except when the load is considerable and the goods bulky, as was the case in the lift cage illustrated in Fig. 8. But little ingenuity was required to alter the design so that the grips were fixed to the bottom frame, and Fig. 10 shows such an arrangement where serrated wedges are used to grip the runners instead of cams.

Another adaptation of the same principle which underlies the efficiency of such gears is illustrated in Fig. 11. The design was submitted to the author as an improvement on the old idea of constructing the cage to fit the well-hole to such a degree that in case of accident the lift may descend on an air cushion. A shutter is hinged at the back of the cage and supported in the front by two springs, one on either side, which are consequently extended on account of the weight of the plate. When the plate is raised up, the safety cams are set by means of levers. This gear gives its owner every satisfaction, but the author would point out the benefit derived is not from the change of air but is due to the action of gravitation.

With improvements in steel wire rope manufacture the lifting chain gave place to a rope, and the single rope, in the case of a passenger lift, to two or four ropes. This greater number is now most common, and the author would here trespass for a moment on ground which received but a cursory glance from Mr. Carey, in his interesting paper on Hydraulic Lifts, read before this Society on the 5th of June, 1893. The author has no hesitation in asserting that when four ropes are used they should each and every one bear an equal share of the work, for the reason that should any pair of ropes be made to carry the load, those running idly would depreciate by constant bending to such an extent, that when suddenly called upon to bear the burden, the dynamic stress would be too great for them and the cage would be left to the action of the safety gear. If a rope, under tension, is bent round a pulley, the resistance will be that due to the bending of the individual wires as beams, plus that due to the increased stiffness given to the wires as a whole, on account of their being laid into one another. The resistance to bending, on the part of the individual wires, is highest where small pulleys are employed, and bending in these cases is often the direct cause of by far the greatest separate longitudinal stress in the wires themselves. If a wire is bent round a pulley of diameter D, the bending moment at any point is $M = \frac{2\,E\,I}{D}$, where I is the moment of inertia of the section of the wire, and E is the modulus of elasticity. The stress, consequently, due to bending is $F = \frac{E\,I}{D}$.

The size of rope commonly used for lifts is $1\frac{3}{4}$ inch circumference, composed of 36 wires of No. 20 B.W.G., with a modulus of 33,000,000 lb. The calculated stress in tons per square inch on each wire, due to bending round a 24-inch pulley, is no less than 22 tons, which is increased to 50 tons on a $10\frac{1}{2}$-inch pulley. The life of such a rope passing round pulleys of different diameters under a load of 14 cwt. is seen in Fig. 12. The diagram is plotted from actual experiments, although it may be doubled if the rope was oiled with the regularity that a chain doing similar duty would be. Again, the life of ropes made in the ordinary way is not more than one-half that of those in which the wires are laid in the same direction with the strands, on account of the cutting action of the wires on one another, which is reduced to a minimum in the type of rope known as Lang's lay.

A consideration of the conditions under which a portion of lift ropes work will show they are not too favourably used, but are subject to reverse stresses whereby the life of the rope is reduced by one-half. The size of pulley required for such a rope, as indicated by theory, according to Professor Unwin should be 28 inches, and this agrees with that determined by calculation from an empirical formula made by Professor Goodman to suit these practical experiments, $(N + 35{,}000)\ (27 \cdot 5 - D) = 880{,}000$, where N is the number of bendings necessary to cause fracture, and D the diameter of the pulley in inches. Thus, when $N =$ infinity, $D = 27 \cdot 5$ inches. It will therefore be seen that manufacturers of lifts do not far transgress by using a 2-foot pulley in order to ensure that the ropes do not wear out rapidly. Now, as regards the practical application of these remarks. How often should lift ropes be renewed ? If a rope of Lang's lay of the size quoted be not oiled, it will stand 75,000 reverse stresses under a tension of about 15 cwt., and this will point to the advisability of changing the ropes every three years in the case of a lift making 200 journeys per day.

The class of safety devices first adopted on the introduction of four wire ropes for raising the load is seen in Fig. 13. A pair of ropes is taken down on either side of the cage, and each is carried to the framework at the bottom on opposite sides of the runners. Each rope is attached to an eye-bolt passing through a guide spindle on the frame, so that all the stress of raising the load is transferred to the bottom of the cage. These eye-bolts swivel on the spindle and pass through a J guide bracket, between which a spring is compressed by a nut to such an extent that if a rope breaks and the stress on the bolt head is relieved, then the spring forces the bolt down to act on the one cam, which at the same time, by gearing, brings the others into play. There is, however, a limiting power for this spring, in order that the gear may not be brought into action whenever the empty cage descends. Such a gear, therefore, has one objection, inasmuch as its efficiency depends on the force of the spring. To overcome this, gears such as are represented in Figs. 14, 15, 16, 17 and 18 are now made. These arrangements vary in appearance as produced by different makers, although all embody the same principle. It will, therefore, suffice to describe one such arrangement, viz. that shown in Fig. 14. The ropes A A are divided as in the spring gear, and each is fastened to the horizontal arm of one of two bell cranks B B. The other ends of the crank levers are connected together by a bar C, so that the movement of one is transmitted to the other simultaneously and the pull of the ropes is balanced. Under the cage two shafts E E pass from side to side, and at each end serrated cams F F are fixed which do not touch the runner G when the lift is travelling. The cams and coupling-bar have projecting lugs which engage one with the other, so that any movement of the cranks pushes one or other cam forward, and all four cams being coupled together by the shafts E E, the action of any one is immediately transmitted, so that each runner guide is gripped on both sides. With this gear the full weight of the cage, &c., brings the grips into action, the crank-pins carrying the entire load. If the arms of the crank-lever in this balance gear are equal, the comparative efficiency of this with the previous arrangement would be dependent on the relative pulls exerted by the remaining ropes, and by the spring respectively against the friction of the cam, which may be supposed to be the same in each case. Fig. 16 is a modification of this gear which is used in the auxiliary lifts of the Blackpool tower.

This gear cannot, however, be considered absolutely perfect, for a unique case has been recorded, in which all four ropes broke at absolutely the same moment. To remedy this a fifth rope, Fig. 17, might be carried over to the cage, not to carry any load, but to bring the gear into action in the event of such a remarkable coincidence as that referred to. The fifth idle rope is, however, capable of doing more valuable work if passed over a governor, as in Figs. 18, 19 and 20, for it would then bring the safety gears into action when the speed of the lift was excessive on its downward journey, as well as act in emergency cases, when the four ropes failed. Governors are without doubt costly if properly made, as they need be in order to work well, and this may be the reason that they are not in greater favour. Another method of actuating the fifth rope, so as to effect the same object as gained by the use of a governor, is seen in Fig. 21. The rope is passed over a pulley at the top of the lift, and away to a small balance weight sufficient to keep a tension on the rope. This rope is attached to the cam or wedge, and from it a spring capable of adjustment is stretched to a fixed bracket on the cage. Should the speed of the cage in descending exceed a certain rate (regulated by the spring) the inertia of the weight will cause an extension of the spring, and so bring the gear into action. This gear, which was patented in England by Mr. Sant, has an advantage over others, inasmuch as the efficiency of its action depends on the square of the velocity of the falling cage, while the others act only directly as the speed of the lift. So rapid and certain in its action is this fifth rope gear, that it is used by itself alone, and the author has tested the same, obtaining remarkably good results.

The author considers the following theoretical consideration of the efficiency of this gear interesting, as exemplifying the simplest adaptation of the elementary principles of mechanics. The strength of the spring usually is such that 7 lb. extends it 1 inch, and the balance weight is made equal to 30 lb., but may, in effect, be equal to as much as double that amount according to circumstances, i. e. the increasing velocity of the falling cage. While the cage travels at a uniform velocity, the tension on the spring only equals the weight, but any increased acceleration immediately extends the spring, and to such an extent that it is necessary to put an initial stress of 45 lb. on the spring in order that the gear may not come into action too rapidly.

To find the relation between the velocity of the cage and the amount of extension of the spring—

Let m = Mass of weight, w = 30 lb.

x = C P (P being point where spring is joined to rope).

y = C Q (Q being point where spring is fixed to cage).

T = Total tension on rope in lb.

E = Original extension of spring = 6·428 inches.

e = Extra extension of spring = $y - x -$ E.

F = Force which will extend spring 1 foot = 84 lb.

Acceleration downwards of cage $= a = \frac{d^2 y}{d t^2}$.

Equation of motion of P is

$$\mathrm{T} - m g = m \frac{d^2 x}{d t^2}.$$

Equation of motion of Q is

$$m a = m \frac{d^2 y}{d t^2}.$$

$$\therefore \quad m\left(\frac{d^2 y}{d\,t^2} - \frac{d^2 x}{d\,t^2}\right) = m\,\frac{d^2 e}{d\,t^2} = m\,(a+g) - \mathrm{T}$$

$$= m\,(a+g) - \mathrm{F}\,(e+\mathrm{E})$$

$$-\frac{m}{\mathrm{F}} \cdot \frac{d^2 e}{d\,t^2} = e + \mathrm{E} - \frac{m}{\mathrm{F}}\,(a+g).$$

Solving the differential equation,

$$e + \mathrm{E} - \frac{m}{\mathrm{F}}\,(a+g) = \mathrm{A}\cos\left(\sqrt{\frac{\mathrm{F}}{m}}\,t + \mathrm{B}\right). \qquad (1)$$

$$\frac{d\,e}{d\,t} = -\,\mathrm{A}\sqrt{\frac{\mathrm{F}}{m}}\,\sin\left(\sqrt{\frac{\mathrm{F}}{m}}\,t + \mathrm{B}\right). \qquad (2)$$

To determine A and B, when t, e and $\frac{d\,e}{d\,t} = 0$, we have from

$$(1) \quad \mathrm{E} - \frac{m}{\mathrm{F}}\,(a+g) = \mathrm{A}\cos \mathrm{B}.$$

$$\therefore \quad \mathrm{A} = \mathrm{E} - \frac{m}{\mathrm{F}}\,(a+g).$$

$$(2) \qquad 0 = -\,\mathrm{A}\sqrt{\frac{\mathrm{F}}{m}}\,\sin \mathrm{B}.$$

$$\therefore \quad \mathrm{B} = 0.$$

$$(1) \quad e + \mathrm{E} - \frac{m}{\mathrm{F}}\,(a+g) = \mathrm{A}\cos\left(\sqrt{\frac{\mathrm{F}}{m}}\,t + \mathrm{B}\right)$$

$$= \left[\mathrm{E} - \frac{m}{\mathrm{F}}\,(a+g)\right]\cos\sqrt{\frac{\mathrm{F}}{m}}\,t.$$

$$\therefore \quad e = -\left[\mathrm{E} - \frac{m}{\mathrm{F}}\,(a+g)\right]\left[1 - \cos\sqrt{\frac{\mathrm{F}}{m}}\,t\right]$$

$$= \left[\frac{m}{\mathrm{F}}\,(a+g) - \mathrm{E}\right]\left[1 - \cos\sqrt{\frac{\mathrm{F}}{m}}\,t\right]$$

$$= \frac{\mathrm{E}\,a}{g}\left[1 - \cos\sqrt{\frac{\mathrm{E}}{g}}\,t\right]$$

$$= \tfrac{1}{2}\,\frac{\mathrm{E}\,a}{g} \times \frac{g\,t^2}{\mathrm{E}}\ \text{(approx.)}$$

$$= \tfrac{1}{2}\,a\,t.$$

$$e = \left[\frac{30}{84 \times 32}\,(32+32) - \frac{45}{84}\right]\left[1 - 1 + \tfrac{1}{2}\,\frac{84 \times 32}{30}\,t^2\right] = 8\,t^2.$$

$$\begin{array}{llll} \text{If } v = 1 \text{ ft. per sec.,} & t = \frac{1}{32} \text{ sec.,} & e = \frac{12 \times 8}{32^2} & = \cdot 09 \text{ in.} \\ \quad = 2 & \quad = \frac{2}{32} & \quad = \frac{12 \times 8 \times 2^2}{32^2} & = \cdot 36 \\ \quad = 3 & \quad = \frac{3}{32} & \quad = \frac{12 \times 8 \times 3^2}{32^2} & = \cdot 72 \end{array}$$

From this it may be seen that when the spring has an initial stress of 45 lb., if the cage falls from rest, the spring will be extended 1 inch in one-tenth of a second, and the cage will have fallen 1·92 inches. This space will be decreased to practically nil when the cage is being lifted, and will be similarly increased (on account of its velocity) if descending at the time when the hauling rope breaks.

This gear was made more efficient and sensitive in 1881 by Mr. Ellithorpe, who caused the weight to travel up and down a tube or casing, as seen in Fig. 22. The weight approximately fitted the casing, and was suspended by a fine wire passing through a small hole in the top of the tube, so that not only the inertia of the weight, but the air compressed in the tube acted together to arrest the motion of the weight and bring the gear into play. With the view of investigating the additional effectiveness due to the compression of the air, the author has recently carried out a series of experiments, under circumstances similar to those which would ordinarily obtain. The results indicated that the pressure on the weighted piston due to the compression of the air was directly proportional to the square of the velocity acquired; and consequently increased the effectiveness of the safety gear to a considerable degree. Each of these latter arrangements would be equally applicable to direct-acting lifts, provided the guides were well fixed.

That gates, enclosures, &c., are necessary appliances for the safe working of lifts the author is willing to admit; but he has excluded such from this paper so that the discussion may be circumscribed. Great credit is due to manufacturers of lifts from the fact that lift accidents are so few and far between, since it is computed that not less than ninety millions of persons are annually carried in passenger lifts in London alone. Makers are always willing to carry out periodical inspections to minimise risks, but this is not so satisfactory an arrangement as work undertaken by an official body would be. The Home Secretary does not, however, appreciate any such good work sufficiently to deal with the matter, but states he "would rather it were undertaken, if at all, by local authorities."

Under these circumstances, and in the absence of any County Council supervision, the author would point out that it might be desirable for the members of the Society of Engineers to combine together to devise an absolutely reliable arrangement. In the meantime, and pending the invention of such an arrangement, the author offers as his opinion that the most satisfactory gear for suspended lifts is a combination of the balanced lever, the inertia of balance weight, and the compressed air gears.

In conclusion, the author trusts that the members of this Society will understand that his object in preparing this paper has been to indicate as simply and accurately as possible the present character and use of appliances for securing the safety of lifts. This he has endeavoured to do in the sense of fulfilling Cæsar's injunction, which the author has taken as his motto—

"Scientia atque usus floreant."

DISCUSSION.

The **President** said it was his pleasing duty to move a vote of thanks to Mr. H. W. Umney for his paper. The members would all agree with him that Mr. Umney had taken a very great deal of trouble in preparing the diagrams and so carefully compiling his paper. There were many present thoroughly conversant with hydraulic lifts, and he had no doubt there would be a good discussion on this paper.

A vote of thanks was unanimously accorded to Mr. Umney.

Mr. **Umney**, in acknowledging the vote, said he was indebted for a number of the diagrams and illustrations from which diagrams were prepared, to various makers of lifts.

Mr. R. H. **Tweddell** said it was some twenty-three years since he had had anything to do with hydraulic lifts, and during that time a great many improvements and additions seemed to have been found necessary. The only accident he had ever had with a lift was in relation to its going up and not coming down; whereas all the precautions referred to in the paper seemed to be taken against the cage falling. Speaking from a general point of view, as an engineer, he thought that the more ingenious those contrivances were, the less likely were they to act when they were wanted. He had recently read a description of an experiment where he considered the maker of the lift absolutely courted suicide. He let go secondary ropes and chains, and came down just as if it was an accident. He demurred against that sort of experiment, because an accident was something quite unexpected. Such a fall was an arranged affair; they were prepared for the lift coming down, and he did not put much value on those experiments. An accident always happened in some unexpected manner, and chains did not break in such accidents in the manner in which they broke in a prepared one. He thought the greatest safeguard for lifts was the good old-fashioned one, of having everything of ample strength and putting plenty of weight into the chains, and fitting the whole apparatus up properly; taking care, above all, that after it left the manufacturer's hands it was properly looked after and maintained. He thought they all suffered a great deal from the fact that after the work left the maker it was put into the hands of an unskilled attendant, seldom or never oiled or looked after; and as for the wire rope, it was supposed to last for ever. When an accident happened neither the attendant nor the owner of the lift were, as a rule, blamed, but only the unfortunate manufacturer. They owed a great deal to the author of the paper. It was a very good thing to have such matters put on record in a theoretical way, but he would warn young engineers not to be too much carried away by formula, or trust too much to the results obtained.

Mr. DRUITT HALPIN said he perfectly agreed with Mr. Tweddell, in fact he went further; his opinion was that all safety gear was wrong, and nine-tenths of the safety gear as it existed was in the wrong place. The author had practically shown only one illustration (that in the perspective view of the ram device) where the safety gear was evidently underneath the cage, and the author gave as the reason for placing the safety gear below the cage, that were the gear in the more usual place, at the top, the bottom might come out of the cage if the gear was suddenly brought into action. He (Mr. Halpin) could not see why the bottom should come out of the cage. It must be made strong enough to prevent the bottom coming out. It always seemed to him that, if a body was falling under those circumstances, the least desirable way to stop it would be to stop it at the bottom. If it were stopped at the top they got a better righting moment; but if they stopped it at the bottom the cage might tend to tip sideways and thus burst the guides out by compression, whereas they possibly would hold if they were merely in tension. With reference to the whole arrangements of guides as they were ordinarily made in this country, he did not mean to say they were actually glued on, but in a great many cases the attachment was very little better, and what would happen if some of the cages came down he did not know. He did not believe in the use of all the safety gear shown, for the simple reason that he thought it gave a false sense of security, and he did not see why it should be used in the case of lifts any more than it was in much more dangerous cases. He was of opinion that the safest way was to put in good gear, quite plain, and look after it properly.

Mr. H. C. Walker said Mr. Umney's paper set forth very fully the history and state of safety gears at the present time. He agreed with Mr. Halpin as regarded the guides of the lift. He thought that they were in many cases put up a great deal too light, and if an accident took place it would be found in some cases that those guides would snap instead of holding the cage as they ought to do. With reference to having one rope, he advocated several ropes, because they would always give signs of wear, and could be watched, and what was taking place could be seen; he advocated a multiplicity of ropes, as there would probably be no necessity to renew the whole at once (although in most cases it might be well to do so), as one might show signs of wear before the others. The object of having a number of ropes was that with a properly constructed gear they should be able to stop the cage on the failure of any one rope, and ensure a number of chances against the cage coming to grief. With reference to the strength of the ropes there was a very great deal to be said. As regarded the inspection and looking after the lifts, makers themselves were not only willing, but glad, for the sake of their reputation, to see that things were in order, and to look after the lifts generally. At the same time, he thought in many cases where the consulting engineer was called in, the manufacturer had a very much better chance, because an independent opinion was taken.

There was one point in the paper where the author spoke about the size of pulleys over which the ropes passed. He mentioned that a 2-foot pulley for the size of rope he gave was ample. He (Mr. Walker) thought, from experience, that the life of the rope depended very largely on the diameter of the wheel over which it passed, and some cheap lifts were made with very small wheels indeed, sometimes as small as 1 foot or 15 inches in diameter. A properly constructed lift should have sheaves not less than about 3 feet diameter. By that means the rope had a chance, because the wearing out of the rope was not from the strain that came upon it, but from the action of passing over the pulley. In guarding against accidents it was necessary to remember that they had to deal with people as they were, and the natural inclination of any one when a lift was descending at an extraordinary velocity was to jump out if they possibly could; and the great thing to aim at was to have a gear that in the case of sudden failure of ropes would absolutely come into action. He could not agree altogether with the statement that had been made that when a rope broke an accident would be sure to occur if the safety gear had not been looked after, because experience showed that ropes in breaking had caused the safety gear to come into action, and lives had thereby been saved, although the lifts had been at work a long time and no special inspections made beyond the usual attention. He thought the point was to make the work as sound as it was possible to be made. Unfortunately, the present tendency was to reduce the price so low that it was impossible to go in for safeguards; but where a proper specification was prepared, and a maker of reputation selected, there should be no difficulty in getting a lift that would not only give perfect satisfaction in working, but would also be as safe as it was possible to make it, humanly speaking, and to work and last well. Considering the number of persons who rode in lifts, the figures given in the paper showed how remarkably well they were made, there being so few accidents.

Mr. HENRY ADAMS said the subject of the paper was a matter he was connected with in the early days of hydraulic machinery. With regard to Fig. 8, although that was called an old form of gear, it was still in use, and had proved efficient on many occasions. There was a reason, he thought, why, in the case of chain lifts, they should invariably have a safety gear. Chains were notoriously difficult to be made reliable, and whether a large chain or a small one were in use, they had both the same area of bearing; they had only one point to work upon between each link, and that created wear and tear and a difficulty of maintenance which was not common to wire ropes, and practically lessened the factor of safety which a larger chain would theoretically give. Where chains were in use he would certainly prefer to have a lift with safety gear. He would not call Fig. 9 a safety gear at all, and he was rather surprised to see it there, because he doubted if there were any lift in existence that would not force the guides out with that gear, or punch through the guides and come down by the levers turning up the other way, if a failure occurred while the cage was loaded. With regard to diaphragms, the first one, he thought, was used by him at the Grand Hotel, St. Pancras, some twenty-five years ago. In that case the hole in the diaphragm was tapered, the larger side being next to the cylinder, to somewhat equalise the velocity of the water passing through under the inlet and outlet pressures.

Mr. R. CAREY said there was one point that had not been gone into very thoroughly, viz. the accident that had recently occurred at Lloyd's owing to the failure of a pipe. He would have liked to have heard an opinion as to the failure of such a pipe. His own opinion was that the most likely accident would be from the splitting of a pipe or the failure of a joint, in which case the lift might possibly come down at its ordinary speed, and the danger in that case would be from persons attempting to jump out of the cage. He was quite sure, from his own experience, that the inclination to do so when one knew the lift was uncontrolled was almost irresistible, and therefore he thought any safety apparatuses that merely controlled the speed at which the lift descended were not perfectly satisfactory, as they necessarily must allow of the lift descending quicker than in ordinary working, or they would act when not wanted, causing alarm and inconvenience. He thought the lift should be stopped entirely immediately on any pipe or joint failing on the cylinder side of the starting valve. It was quite possible to devise such an arrangement. For instance, assuming that a pipe split and the water was escaping at exactly the same speed as it ordinarily passed through the valve, the lift would descend, and the only difference between the ordinary working of the lift and the conditions then existing would be that the valve and controlling gear would not be in a position for lowering. It was quite possible to make a mechanical arrangement that should prevent the possibility of the lift descending unless the starting mechanism was in position for descent; such a lift would be much safer than one only fitted with the ordinary safety apparatus. The principle might be applied to direct-acting lifts equally with suspended ones. The better forms of safety apparatus were brought to such perfection at the present time, that danger from the failure of a rope, or rather the whole of the suspending ropes, was nearly out of the question. There was not much danger from the failure of one rope; when there were four that form of danger was well nigh eliminated by the very perfect safety apparatuses now in use, especially when the only duty of the fifth rope was to put the safety apparatus into action. It was scarcely possible to imagine that even if all the ropes were to break simultaneously, the fifth rope would not act perfectly, as it took such a very slight pull to put the cams into action that it could be done easily by the finger. If moderately well looked after and kept clean, the liability to failure would be almost *nil.* The runners or guides on which the cams gripped might fail if they were not strong enough, but that was not a part of the safety apparatus, it was part of the construction of the lift. He quite agreed with Mr. Halpin that all parts of the lift should be made of adequate strength; but although the lift might in all parts be perfectly strong enough for its work, he saw no reason why a safety apparatus should not be added, even if there were very little fear of any part of the machine breaking. A safety apparatus could not do any harm of itself, and he thought there should be one.

Mr. F. **Eastmead** said that the valve shown in Fig. 6 seemed to him rather apt to dance in ordinary work, and he would like to know whether it had been found to do so, as that would cause a jerky motion of the car. The one shown in Fig. 7 appeared to him rather more desirable. With regard to the question of using those valves on suspended lifts, he did not quite understand whether the author recommended them at all for that purpose; but if they were used there, it would be rather going to the wrong end of the machine, because it seemed liable to carry something else away, owing to the sudden stoppage there—that was if the hole in the valve was only a quarter of an inch. The author had referred to the oiling of the ropes, but he (the speaker) did not think he had given sufficient attention to that matter. The author said that if a rope of Lang's lay was not oiled it would stand 75,000 reverse stresses under a tension of about 15 cwt., and last about three years. Supposing that rope was properly oiled and looked after, how long would the author expect it to last then? His experience showed that efficient lubrication more than doubled the life of the rope.

Mr. J. T. **Milton** said that most of the previous remarks had been made by lift engineers, and a few remarks from himself, from the lift user's point of view, might be useful. His attention had been drawn a great deal to lifts lately, owing to the unfortunate accident that had been mentioned, whereby he lost a very valuable colleague. It appeared to him that instead of safety gears being, as one speaker said, nearly perfect, they were very far from being perfect. He had always thought that the velocity was a mere nothing, but that it was the sudden stoppage of velocity which constituted danger. He took it that any safety gear depending for its action upon the velocity of the lift was absolutely useless. There were other safety gears that might work perfectly well if the lift was at rest, and then was started through an accident; but how would they work when the lift was coming down at its ordinary speed if something gave way?

With regard to Fig. 13, he thought if that gear acted at all it would act by causing a dead stop, which was really the danger to be avoided, and they might almost as well go down to the bottom and stop dead there. He had never seen a lift so arranged that it would stop at the bottom in an easy manner. All lifts, without exception, even fitted with the most approved safety gear, should have some means of stopping gradually at the bottom in case the safety gear did not act. Like all other things, it must be expected possibly to fail at some time or other. As a rule, many safety gears were applied to lifts with four ropes, and they were applied to obviate only the result of one kind of accident, the breakage of one rope. That, he thought, was the last thing they need trouble about. If they had a lift fitted with four ropes, each one capable of carrying the lift, if one broke there were the other three left. The chance of all four ropes breaking simultaneously seemed to him to be infinitesimal, far less than that of an accident arising through the failure of some one part of the other gear. Whether it was a suspended lift or a direct-acting lift, there was always a lot of gear, and if it got out of order only in one point it might lead to disaster. For instance, there was the starting valve lever; it was generally worked on a pin with a split pin in it to keep it in its place. If that split pin got out, and the attendant did not see it, the pin might come out; the control of the starting gear was gone, and the lift might go out through the roof or stop dead at the bottom. That was an accident which might happen with any kind of gear. Then there was the difficulty to be faced of the breaking of the pulley, or other parts of the mechanism failing.

With regard to ram lifts, the only gear he had seen applied to that kind of lift was the valve shown at Fig. 6. That gear was open to exactly the same objection as he had been raising. It did not attempt to work until the ordinary velocity was exceeded. Gears that operated on the ram brakes, and so on, would not work unless all, or nearly all, the pressure in the cylinder was lost. Supposing Mr. Umney's figures of Lloyd's lift were taken as being correct, they had a ram lift that worked under ordinary circumstances with a pressure of 300 lb. per square inch in the cylinder. That was the minimum pressure when the lift was running light. When the pressure, from a burst pipe or any other cause, was reduced to, say, 250 lb., the grips came into operation. That lift, if it had to work at 300 lb. pressure as a light lift, might reasonably be supposed to work at at least 400 lb. as a loaded lift. Suppose that, when working as a loaded lift, there was a rupture in the pipe, or something of that kind, which reduced the pressure to only 300 lb., nothing would happen to the grips whatever, because they must be arranged so that they would not come into play when the lift was running light. But if they had a lift loaded to a pressure of 400 lb., and had only 300 lb. in the ram cylinder, and had a fall of, say, 100 feet, the lift would go to the bottom with an acceleration one-quarter that of gravity, and would attain a velocity of 2400 feet per minute, and a very serious accident would happen when it stopped dead at the bottom. The velocity would be the same as a free fall through 25 feet.

He thought that all safety gears should be based not on the velocity attained by the lift at all, but on the acceleration. When an accident occurred there was an increase of acceleration, and that was what should be made to bring the safety gear into action before any excessive velocity had been attained. That was not an impossibility; it could be done, it was being done, and he hoped soon to be able to say it was done successfully. He had seen experiments made at an engineering works where that principle had been worked out. It was not complete in all details, and therefore he would say no more about it; but he was quite sure from what he had seen that it was a feasible thing to do, and in that case the gear could be applied equally well if there was an acceleration when the lift had attained its ordinary velocity in ordinary work.

The author said in the beginning of his paper that one of the serious things to happen in a lift was the hammer action. Now the hammer action, and a great many other difficulties in a lift, were matters which, to a large extent, were controlled by the attendant, and he felt very strongly that if they put up a lift or any appliance on which the safety of human life depended, they ought to take all reasonable precautions that the man who controlled that lift should be a careful, steady and competent man. He had seen a great many lifts, and he had seen a great many lift attendants, some of them mere boys. Not long ago he was at a very important building where they had a hydraulic ram lift, with an adult attendant in uniform, and everything in appearance to give confidence; but when he went into the basement of the building he found it was flooded with water, and he found the gland was leaking very badly, and the attendant, apparently, was not competent to pack the gland or even to tighten it. There was no earthly reason why such a thing should be: there were plenty of men who were quite competent to work lifts and their gear, who could be obtained at reasonable wages, and there was no excuse whatever for any lift user to employ an incompetent man for the sake of saving a few shillings a week.

Mr. Walker had stated what he (the speaker) felt very strongly about, viz. that many of the safety appliances, if they were called into play through all the four ropes breaking at once, would be found wanting in strength, especially if they happened to be called into play when the lift was descending.

He (the speaker) had never seen a so-called guide or runner yet that he would like to trust a descending loaded lift to. He had seen something on the principle shown in Fig. 13, a narrow strip of wood screwed on with a few screws to another piece, which was screwed on to a few wood bricks built into the wall, which after a year or two shrank. As Mr. Halpin had said, some of them might just as well be glued on for all the good they were.

The author said in his paper, "This shock is in no way transmitted to the mains, as consumers are always required (where the supply enters their premises) to fix a valve, which shall not only act as a stop-cock but also as a back-pressure and retaining valve, in order that any failure in the power supply will not affect the machine so as to cause it to descend." Those valves were a very possible source of danger. They were no doubt in perfect order when they were fitted, but his experience was that inside water pipes of lifts in London—it might be the same in the provinces—there was a certain incrustation of rust which formed in the pipes and was carried into the mechanism. The valve, as he had seen it, was an ordinary non-return valve with a screw-down spindle at the top. When the spindle was lifted up there was 700 lb. pressure in the main to lift the valve; when work was done for the day there was the screw spindle to screw it down. A very little corrosion would make that valve stiff. It would still probably be lifted by the 700 lb. pressure, and it might still be screwed down by the spindle, but it would not fall with its own weight, and unless it was free enough to fall with its own weight it was useless for a back-pressure valve. If some of the pipes in the streets were cracked or eaten away by electrolytic action, and a failure took place there, down came the lift.

The gear shown in Fig. 13 was one that he had often seen, as it was very commonly applied, but he had never yet seen it at work, or even seen all its parts. The ordinary requirements of construction of the lift cabin put part of the gear out of sight. The author drew attention to the fact that the whole safety of that gear depended on the efficiency of the springs, but although the gear, no doubt, was put in in perfect order, after it had been in use three or four years how did they know that the springs would act, seeing that the springs were out of sight? Every piece of mechanism which could possibly get out of order in any lift should always be accessible.

There was another point he should like to mention which had nothing whatever to do with safety appliances, but seeing there were several lift-makers present, he would urge upon them never to make any lift cabin with a closed-in top. If his firm's lift had had an open top his late colleague would have been his colleague to-day. He saw no reason for the closed-in top. If there was any reason, it was to prevent things being thrown down on the lift, but that could be provided for in some other way. If a man in a lift found that it was running away, he had an almost uncontrollable impulse to get out of it, and it was the closed-in top that killed people. Speaking of that sad accident, the author had made a mistake in one of his figures in the paper. He led an unskilled man to think that the lift had actually attained a speed of 700 feet per minute, but Mr. Read was killed before the lift fell five feet. The speed then was nothing like that which the author gave as the speed of the lift. In fact, the lift would never have attained the speed the author mentioned. It was, however, not speed that killed; it was the stoppage. The members should bear in mind that it was not velocity, but acceleration, which led to all the danger.

Mr. A. C. MOFFAT said, with regard to the acceleration of the cage before the safety apparatus came into action, it had never found favour with him, because when increased velocity was attained by a cage, which in itself was a great weight and which was weighted with passengers, the cage was descending so fast that any sudden grip put on by an apparatus such as the Otis gear must cause some breakage. The same remarks applied to the apparatus underneath the cage of Fig. 14 that had been made with regard to being out of position for accessibility. He had seen such apparatus not come into action when the cage had fallen, and on inspecting it he had found that it had not come into action because it was clogged up with bad oil, dust, &c. It had been beyond the reach of the attendant, or had not been within sight, and therefore it had been neglected. He always maintained that the proper place for a safety apparatus was at the top of the cage, where it could be easily got at and always seen. He had witnessed one or two cases where a safety apparatus had come into action. Lately he had seen two instances with one lift. They had heard to-night solely about hydraulic lifts (which were usually fitted with more than one rope), but there were a great many other kinds of lift, those driven by belt or electricity. The case he referred to, in which an accident occurred twice, was a lift with spur gear, in which only one rope was used, so that the principle of the balanced lever safety gear was unsuitable, and from some cause or other an overhead spur wheel broke The rope, of course, was dislodged, and the apparatus came into action immediately, before the cage had any acceleration. A new wheel was placed in, and ten days afterwards the same thing occurred again. The reason had not yet been found out. The cage descended in the ordinary way until the wheel broke, and the safety apparatus came into action and prevented loss of life. The apparatus was on the top of the cage. The guides did not give way in the manner that had been supposed. He thought that the question of safety apparatus should not be confined to hydraulic lifts, but should be extended to those driven by belt.

Mr. Maxwell Williams agreed with what the author said in regard to the inspection and periodical testing of hydraulic lifts. He would ask the author what he would consider to be the proper testing of a lift. He (the speaker) was acting for a firm who proposed to put in a new lift, and a few days ago they went to look at one which was used for passengers and had a cam safety gear on the top. It was out of doors, and the height travelled was from 70 to 80 feet. It was a very good lift, and made by well-known London makers. He said, "I suppose you test this occasionally," and the foreman replied, "Yes, we test it sometimes." He added, "I suppose to do this you lash it up with a lashing, lower out an inch or two, and then cut it," and the foreman said that was the way it was done. He said, "Next time put the two managers inside, and see how they like it!" The foreman saw the point, and he (Mr. Williams) told him it was no use testing a lift empty like that, and next time to put in four or five sacks of coal, which would be equivalent to four or five people going up. The safety gear of a lift out of doors would, of course, be liable to get frozen up, and was also exposed to the rain, and therefore it would be no use at all if rusted up.

Mr. F. E. Duckham said the hydraulic lift machinery with which he had had to deal had been chiefly in the shape of cranes, where safety had been ensured by making everything several times stronger than needed by the actual strain ever likely to be put upon the crane. In following that out in practice there had been great freedom from accident. In connection with passenger lifts, the question of safety was a very important one. The number of people using lifts was so great that it was necessary there should be some inspection of such lifts, in the same way as railways were inspected and passed by a Government official. The method of applying safety appliances to lifts was a somewhat difficult problem. The two principal things that had to be provided against were (1) the failure of hydraulic pressure, and (2) the failure of the rope or chain gear; and those two things had probably to be provided for by two different appliances, unless something be invented which would be acted upon immediately by the acceleration in the descent of the lift. Some years ago he had to deal with a lift of 70 tons capacity, and it was considered an absolute necessity that there should be some safety appliances. The lifting gear consisted of four horizontal cylinders having two sheaves each on the rams; in that case he fixed four vertical bars 4 inches square, viz. two on each side of the lift platform. There was a pair of grabs on each bar, and these were held out of contact with the bar by a trigger arrangement which was actuated by a strong spring, and was put out of action by a screw at the back of the catch of the trigger. At the end of the trigger lever there was a line or a light chain, which was led away to auxiliary sheaves on the lifting ram, so that when all was right the movement of one synchronised with that of the other; but if, as once happened, the main lifting chain broke, a strain was brought on, the little chain pulled off the catch which kept off the grabs from the guide bar, and the grip came immediately into operation before the lift had gone down a foot. That arrangement was effective, but he did not quite see how the same thing could be universally applied to passenger lifts, for it did not meet every case, such, for instance, as when the bursting of a cylinder or pipe allowed the water to escape suddenly.

Mr. Perry F. Nursey said, as regarded the cause that rendered accidents possible, he thought that Mr. Walker and Mr. Milton had both exactly indicated it. Manufacturing engineers turned out lifts of the best design and construction, and after they had erected them and put them in sound working order, the lifts were often left to the mercy of attendants who knew nothing at all about them, and who worked them in an utterly reckless manner. He knew of one lift in particular, in the city, where the attendant was absolutely reckless, and shot passengers up like an arrow from a bow, and then stopped suddenly, and also brought them down in the same way. He (Mr. Nursey) had spoken to him on the subject, and he had replied that if he did not know his business he would not be placed there. That young man, however, was not in charge of that lift now. The remedy that suggested itself to his (Mr. Nursey's) mind was that manufacturers and users should enter into an arrangement whereby periodical inspections should be made by the manufacturers under a guarantee, and that the manufacturers, for a reasonable fee, should hold themselves responsible for the safe working of the lift year by year. He thought that would be an arrangement which would meet all requirements, and would, when known, be a guarantee of safety to the public. Another point which occurred to him was with reference to the manufacture. It was said by Mr. Walker, and very truly, that competition was so keen that prices were cut down in lifts just as they were in other branches of trade; consequently, lifts were often made and put up at a merely nominal price, which meant that the cost of production was reduced to the lowest limit, thus dangerously reducing the margin of safety. He believed that the better class of manufacturers would absolutely refuse to make a lift under those circumstances, and he hoped that no manufacturer would accept a contract which necessitated his cutting prices so close as to involve the remotest chance of any risk of accident, seeing that it was a serious question of danger to life. He knew an old-established firm of rope-makers, with a reputation to lose, who under no circumstances could be induced to make a second-rate article, and he hoped that lift-makers acted on the same principle. He would again express his conviction that responsible periodical inspection would, in the main, prevent the occurrence of lift accidents, and he hoped to see it adopted.

Mr. Druitt Halpin said that, as a matter of fact, he thought 95 per cent., perhaps, of all the lifts in London were inspected and maintained by the various people who put them up. The author had touched slightly on the question of gates and fastenings, and they certainly gave engineers infinitely more trouble than everything else put together. It was very hard to get them right, and get them so easily worked that they would be looked after and would be perfectly safe. He quite agreed with what the various speakers had said about attendants. He had a case some time ago which he was very sorry to have to deal with in the way he did, but there was nothing else to be done. He examined the attendant and questioned him, thinking there was something wrong, and he found out that the attendant had met with an accident to his head some years before and was hardly in his right mind. They had to get rid of him at once.

Mr. Nursey said he was very glad to hear what Mr. Halpin said. He was not aware of the fact. He hoped the inspection would be extended to the attendants, as they were very important factors of safety.

Mr. R. J. G. Read said Mr. Eastmead had had to do with the Blackpool tower lifts with him (Mr. Read), and was responsible for working out all the details of the hydraulic machinery. He had hoped that Mr. Eastmead would have given his experiences on the subject. The main lifts ran 325 feet at a single stroke in one minute. The small lifts only ran up to the 50-feet floor, and the main lifts started where the small lifts ended. When they were getting out the designs for those lifts they considered very seriously the matter of safety, and although he was of the opinion that the main thing was to have a good margin of safety in the ropes, and make the whole thing perfectly simple and workable, still that did not satisfy everybody, and if they had attempted to put one single rope with a very large margin of safety to carry the lift, the directors would not have considered it sufficient. Therefore, they were driven to adopt some safety apparatus, and in that case their safety apparatus was arranged on the side of the lift, not on the top or the bottom, but about the position A in Fig. 14. It consisted of very powerful railway springs actuating two brake blocks, which clasped the guides on each side of the cage. He felt the importance of making the guides strong, from seeing the small timber guides in the ordinary lifts. Therefore, in the tower the guides were made of rolled joists, about 12 inches by 6 inches, backed up by channel irons, where necessary, to give them depth backwards as girders. Their greatest height or span was about 40 feet, and higher up the tower, where the spans were smaller, they were reduced in section. Those guides were made specially strong, to stand the shock of a descending lift, in case the safety gear came into action.

The details of those lifts were all worked out as carefully as could be, with the view of perfecting the apparatus. When the drawings were complete they were submitted to Mr. Halpin, who examined every detail. The lifts were made and erected, and Mr. Eastmead, after he had made the drawings at Mr. Heenan's works, had charge of fitting up the lifts in the tower and working them. When it came to the testing of the lifts, Professor Charles Hopkinson of Manchester came on behalf of the insurance company to test them, and he (Mr. Read) was with him at the time. Mr. Eastmead had charge of the testing, and it was a very interesting and anxious thing for them to know what would be the shock on the guides if the safety gear did come into action. The lifts were capable of carrying about forty people each, so that it was a very serious thing having that number of people in a big cage going 325 feet in one minute. They loaded them first of all, and ran them up and down and tested them with as much as they would carry, letting them come down to test the effect of the shock on the guides. The lift was loaded with bags of cement, Mr. Eastmead and another got inside, he (Mr. Read) got half-way down the tower, and Professor Hopkinson got about 10 feet lower down. He (Mr. Read) was to give the signal to the man to knock out the safety gear so as to put it into action, with the idea that Professor Hopkinson would be able to see the effect of the stopping by the time the cage got to him. The lift came down at a tremendous rate, and Mr. Eastmead, who was inside, thought the speed was 1500 feet a minute. The moment the signal was given the man knocked out the safety gear and the lift stopped dead. He did not think it went 6 inches on the guides, and the whole weight, about 12 tons, was held tight. The shock was very little on the ironwork of the tower. He had been in the lift himself several times when the safety gear was put into action, and the lift had stopped, both when going up and coming down, without any ill effect from the shock. As regarded the knocking out of the safety gear, that gear was made to come into action by one of the ropes breaking. There were four ropes, each one more than capable of lifting the car itself, but in case either of those ropes broke or stretched it upset the balance of the lever, and put the two railway springs before mentioned into action, which put on, by means of toggle levers, the two brake-blocks at the side. Those springs required about 2 tons to compress them, and they put on about 13 tons to the guide. As they could not cut the ropes and let go entirely, they simply let the cage run freely down, and then instead of the safety gear pulling the lever out of balance, they had a man with a big hammer who knocked it out so as to set the springs free. It answered very well so far, and had done so on several occasions. He merely gave those particulars to illustrate the effect of the shocks in testing the lifts—of course, as Mr. Tweddell said, those things were all arranged, but they had to do something. If the lifts were required to be tested, some means must be devised of testing them, and such devices of course were not true accidents. He sincerely hoped there would no true accident happen to the lifts in that tower.

Mr. W. Worby Beaumont said he had lately seen a form of lift grip which seemed to offer some advantages over the forms shown on the diagrams. The nearest approach to it was shown in Fig. 2, in which a pair of gripping blocks were brought to bear on the ram by means of so-called levers and a piston working directly on them. That which he had seen had been devised by Mr. J. Conrad Cole, and instead of levers acting on brake blocks, there was a small differential piston, acting on a pair of levers connected with two right and left-handed screws. These screws did not simply hold a pair of blocks pushing on the two opposite sides of the ram, but extended like a clip almost completely round the ram, so that instead of needing a very large pressure to get a certain amount of grip, a comparatively light pressure was all that was necessary. The arrangement was one applicable to almost any lifts of the ram kind, and could, he believed, be placed so that it was always accessible. Mr. Halpin seemed really to have hit the most important question with regard to the other lifts, viz. those that were in work with rams, when he pointed out that the great complication was brought into the lifts by adding parts simply to take the place of others should they break. In other classes of machines sufficient strength was put in so as to prevent accident by breakage, and then with proper attention accidents very rarely occurred. He thought simplicity with very large factors of safety should be aimed at. The arrangement shown in Fig. 11 was something in the nature of a gravity-checking mechanism, and appeared to him to be one of those which were really never satisfactory.

With regard to the testing of lifts, a form of safety gear described as the Otis gear was that which was adopted in one of the lifts at the Eiffel Tower in Paris, and it was tested by actually cutting the ropes and letting the cage fall. Of course there was a great difference between a test made in that way and an accident that might happen, or rather the test which would occur if any of the ropes suddenly broke when the lift was actually ascending at any speed. The pull upon everything would of course then be vastly greater, but still it was really a very fair test, and he had seen that apparatus at work and brought into action very rapidly indeed. He did not think there was anything wanting as regarded the rapidity with which it came into action, but there was the question of the desirability of bringing the apparatus so suddenly into action. He would emphasise what others had said as to enormously increasing, not only the strength of the guides, which were often very light indeed, but improving the construction generally. Mr. Read had mentioned guides which appeared to have had factors of safety of several hundreds, but he thought that in many of the lifts at work the factors of safety with regard to the guides would be perhaps nearly as much as one.

Mr. C. G. MAJOR said that the tendency of the remarks of some of the speakers had been rather to depreciate the value of safety gears. It would be a great pity if the value of safety gears should be lowered at all by the present discussion. They had been told what a lift attendant ought to be. They could not get him; he never existed. The ideal man was not engaged, but a boy or a man who knew nothing at all about machinery. Mr. Tweddell made some remarks which would meet with the sympathy of all manufacturers, in which he referred to the bad treatment that machinery received at the hands of the user. That bad treatment had to be faced. However strong the machines were they would wear out, and a lift rope was allowed to go on until it broke. It was left to take its own chance. There was no inspection, unless it could be carried out by themselves under such contracts as had been alluded to. Ten per cent. of lifts ran without any inspection at all, and in spite of that, if an accident happened, the lift-maker was blamed. Therefore they must put in safety gear and provide for all the results of bad treatment. As to the action of safety gear, they had been told that prepared accidents were not really accidents. That was perfectly true. One gentleman had pointed out that accidents must be manufactured in order to test the gear; but as the parent of the gear shown at Fig. 14 he might be allowed to say that on large and small machines there were now between 500 and 600 of those sets running, and during nine years they had on record over 60 accidents, unexpected and occurring in the ordinary course, and in no case had the gear failed. Out of the 60 about 20 were passenger lifts, and in some cases passengers were in the lift, and no bad result had happened. It acted before much speed was gained. With a good gear it would act immediately on the failure of one rope: the lift was held up by the other three ropes, and it was pulled up while travelling only at its ordinary speed. It might be safely pulled up at that pace, and no trouble would result. Another speaker had rather relied upon the value of four ropes. It would be a most disastrous thing to cultivate the opinion that four ropes, or any number of ropes, were a precaution in themselves without proper safety gear. When one of the four, or one of the series, had sufficiently worn out to break, the others were not far off. If there were four, and one broke, each of the three would have to take its share of the suddenly released strain, which they could not stand, and hence came what the author had referred to, probably erroneously, as a supposed case of four ropes breaking simultaneously. He did not think that had ever occurred, or ever would occur. What did happen was probably what he had suggested, namely, that one broke and the others followed, owing to the added strain. Had there been a safety gear, which would have acted on the breakage of one, the other three would not have broken. He knew of a case, only within the last six months, in which four ropes apparently broke simultaneously, that was to say, within the space of half a minute. It was so quick that no eye could see it. If there were any apparatus attached to those ropes which would stop the strain being transferred from the broken one to the others, then the three remaining ropes would be left intact. The author had referred at the beginning of the paper to grips. There was one illustrated at Fig. 3 for ram lifts. He (Mr. Major) had designed one of those, and set it in operation some ten years ago, and it had been found to act very well indeed so long as it was in operation, but it was not constantly wanted, and like all things that were not wanted it got set fast. About three years after it started it was tried and found to be just a solid mass of metal. That was the danger attending all such appliances. If a safety gear was to have any value, it must be constantly worked with the machine, not left to act suddenly on an emergency.

Mr. Umney, in reply, said that Mr. Tweddell commented on the fact that safety gears were placed at the bottom, and preferred that they should be placed at the top. It was, no doubt, easier to get at top gear if in an enclosed lift hole, but it necessitated a considerable increase in the weight of the cage, and consequently increased weight of all the moving parts, and those were matters to be avoided if possible. Mr. Tweddell referred to a test of a lift he had seen described. He could not agree with Mr. Tweddell that that test was a poor one. He considered it the best that could be got. The lift attendant was doubtless often the person who brought about disasters by suddenly starting and stopping the lift. Skilled lift attendants were very nice if they could be got, and it paid to keep such, because they kept the machinery in good condition, and, in general, were far more satisfactory, giving the passengers greater confidence than a boy's presence could. Mr. Halpin also preferred that the safety gear should be at the top of the cage, and he objected to the multiplication of safety gears. Had Mr. Halpin ridden in cages and worked lifts continually, he would have known the questions with which the lift attendants were generally taxed by passengers, who invariably asked what would happen if the lift fell. If the attendant could only tell them there were numbers of safety apparatuses, he would be much more happy. Mr. Halpin said it was, moreover, unnecessary to have more than one safety apparatus, but he (Mr. Umney) thought it was customary on railway trains to have more than one brake, so that the guard could stop the train in the event of the driver (a skilled attendant) running past a danger signal. Mr. Halpin also objected to the way guides had been put up, but he (the speaker was confident Mr. Halpin could never have seen any he had fixed, for his were well screwed closely together, and not glued up.

Mr. Walker commented on the size of the pulley which he (Mr. Umney) had referred to as being only 2 feet, but he would point out that the stress under which those ropes were working was 15 cwt. only, and were his (Mr. Walker's) 3-feet pulleys put in, it would be found that the working stress was considerably more than that.

Mr. Adams, while approving of the gear shown at Fig. 8, objected to that in Fig. 9, where the spikes pushed out on the face of the runners, and he seemed to doubt if they were now in use. He (Mr. Umney) said that they were in use, for he had seen them recently, and the runners were ploughed down from top to bottom.

Mr. Carey pointed out the danger that was run by people jumping out of the cage, and plenty of precautions, such as gates and the like, had been suggested. Mr. Martin, of Manchester, had recently brought to notice an automatic hand-rope gripper and protector. There was a handrail which went across the front of the cage, and while in front of the cage the starting-rope was released. If open for the passengers to pass in or out of the cage, the rope was gripped and the lift could not be moved.

Mr. Eastmead devoted his attention first of all to the valves shown in Figs. 6 and 7. Fig. 6 was a design of Messrs. Waygood and Co.; Fig. 7 was Mr. Harris's patent. The insides of those valves could not be seen at work, and therefore he was unable to say whether No. 6 did dance or not. Dancing was a very nice exercise if it kept the springs in working order, and so gave them the daily use which safety appliances needed to be subjected to. Certainly such valves might be applied to suspended lifts, but they were absolutely unnecessary if diaphragms were used. He had included in his paper some six designs:—Fig. 14, Smith and Stevens; Fig. 15, Otis Elevator Company; Fig. 16, Eastmead; Fig. 17, Waygood; Fig. 19, A. and P. Steven, of Glasgow; and Fig. 20, Middleton, of Leeds—all of which were on the balance lever principle; each one was patented, and they were absolutely the same in principle.

Mr. Milton objected to the safety gears which depended upon velocity, and said they were absolutely useless. He could not agree with him, because he knew, from recent experiments, that the gear shown in Fig. 21, which acted directly as the square of the velocity, worked admirably. As regarded the difference in the shock of being stopped at the bottom of the lift-hole, or after falling only a few yards, he would ask Mr. Milton if he had ever tried jumping down a few feet and jumping down 20 feet. The shock was not quite the same. Mr. Milton referred to the bursting of pipes in reference to ram grips, and said that, under working conditions, when the lift was loaded and the pressure 400 lb. or more, if the pipe broke and the pressure did not fall to 300 lb., then the ram would not be gripped. But if the pressure did not fall below 300 lb., then the lift would not descend at more than its normal speed, and hence gear would not be required. Mr. Milton also said that his retaining valve stuck if not attended to; but if Mr. Milton was going to have one part of his machinery periodically inspected, he should have his valves attended to at the same time. Surely one part was every bit as important as the rest. The springs, too, might equally be periodically inspected, and not, as usually they were, by merely the ordinary working mechanic. Mr. Milton rather doubted the speed given in the paper of Lloyd's lift. He said it only fell 5 feet before Mr. Read was killed, but in 5 feet it would have acquired a maximum velocity, and that velocity he (Mr. Umney) still ventured to think would be 700 feet per minute. The friction on the ram would be mostly overcome in the first foot or so, and that friction was not a serious amount in a direct-acting lift. Mr. Ellington, in a paper read before the Institution of Mechanical Engineers in 1882, gave something over 80 per cent. efficiency for such machines. He (Mr. Umney) did not think the friction would make much difference, and the speed would be very nearly attained at the end of the first foot.

Mr. Moffat could not find any safety gear for application to belt-power or hand-power lifts. He (the speaker) would draw his attention to Figs. 2, 3, 4, 5, 6 and 7. They were all equally applicable to the cages raised by one rope or chain.

Mr. Read had given a very good description of the lifts at Blackpool tower. The gear shown at Fig. 16 was Messrs. Eastmead's make, and was the same as that used at Blackpool.

Mr. Beaumont had said that the gear shown at Fig. 11 did not appear to be very satisfactory. The inventor termed it his "wind gear." The lift was erected in an open shop. There was a corrugated iron shutter hinged at the back of the cage, connected in the middle by levers to the usual cam shafts, and supported at the other end by springs on both sides, a small weight being added to the shutter in order to give the springs an extra tension. The lift rope was cut in the usual fashion when testing it, and only fell a little way. The inventor seemed to think it was the wind actuated the gear, but he referred the inventor to a very simple experiment, namely, to get two pound weights, join them together with a piece of elastic, hold the top one, and let the bottom one stretch the elastic. When the upper weight was released the bottom one would be found not to move appreciably at all till the top weight had fallen to such an amount as the elastic had stretched.

Mr. Major had observed how necessary it was that safety appliances, when used, should be such that they were put in use daily, and not once in a way. He (the speaker) pointed out that the safety appliances, Figs. 18, 19, 20, 21, 22, were very nice gears, since they acted as governors; for when attendants, as they often did on their downward course, over-filled the lift and attained an excessive speed, the apparatus was brought into use. There was but one other way to make lifts safe, and that was to institute a system of rigid supervision.

FIG. 1.

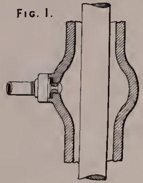


FIG. 2.

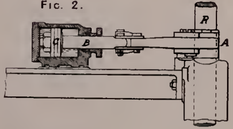


FIG. 3.

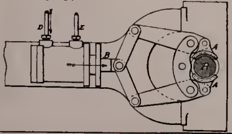
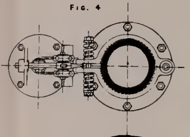


FIG. 4.



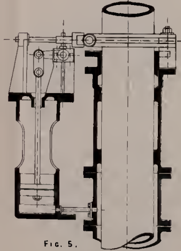


FIG. 5.

FIG. 6.

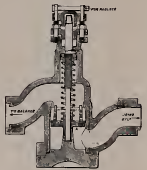


FIG. 7.

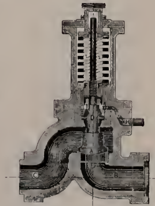


FIG. 8.

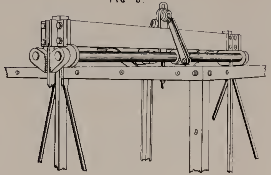


FIG. 9.

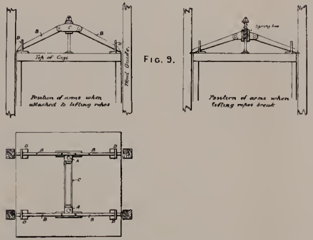

D
B
C
B
D
Top of Cage
Wood Guide
Position of arms when attached to lifting ropes
Spring box
Position of arms when lifting ropes break
D
B
B
D
A
C
A
D
B
B
D

FIG. 10

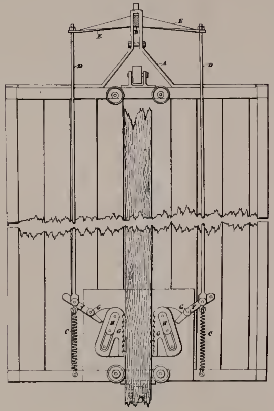


FIG. 11.

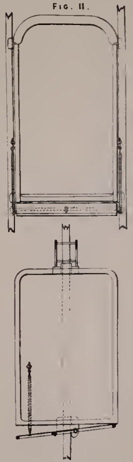


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FIG. 12.

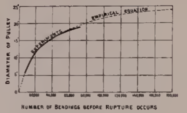


FIG. 13.

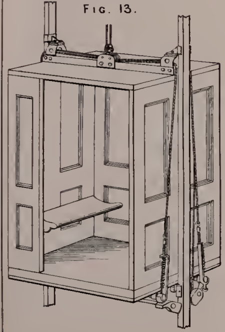


FIG. 14.

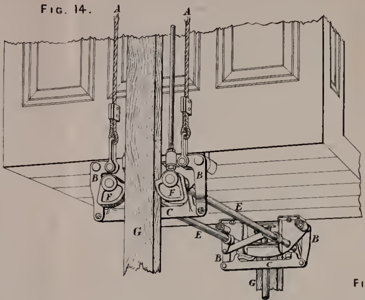


FIG. 15.

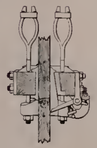


FIG. 16.

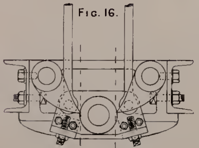


FIG. 17.

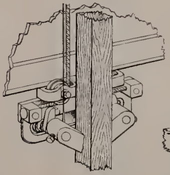


FIG. 18.

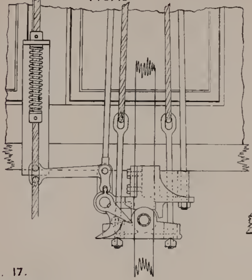


FIG. 19.

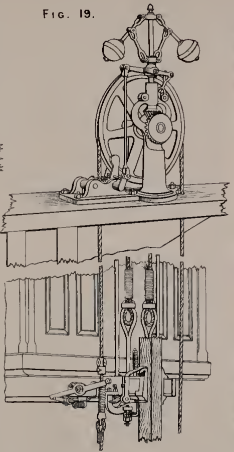


FIG. 20.

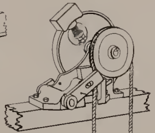


FIG. 21.

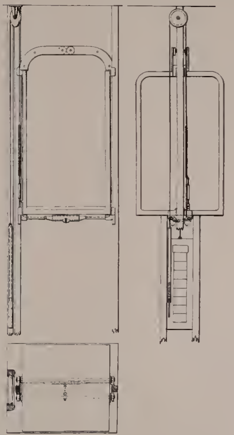
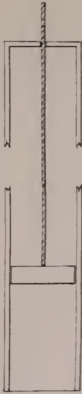


FIG. 22.



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VACATION VISITS.

During the Vacation of 1895 the usual Vacation visits were made to works and establishments of professional interest. There were three of these visits, the first, on June 12, being to the works of the Waterloo and City Railway (in course of construction) and to the New City of London Brewery. The second, on July 3, was to the Outer Harbour Extension Works, the existing Harbour and the Electricity Supply Company's Station at Dover. The third, on October 2, was to the School of Gunnery and the new experimental ranges at Shoeburyness.

The following are general descriptions of the several works.

Waterloo and City Railway.

The Waterloo and city railway, which will be an underground electrically worked line, is being made in order to enable passengers between the London and South Western Terminus at Waterloo to reach the very heart of the Metropolis with greater ease than is possible with existing facilities. By this new line passengers will be able to get from Waterloo to a point near the Mansion House, without stoppage, in about four minutes, at an average speed of about 22 miles an hour. To this must be added the time occupied in passing from the South Western arrival platforms to the subterranean terminus, and from the city terminus to the surface. The departure platform of the electric railway at Waterloo will be about 36 feet below the South Western platforms, while in the city the depth below the surface will be 65 feet. At the latter place lifts will be required, but at Waterloo it is proposed to have easy inclines, with a few stairs at intervals. The line commences at Waterloo at right angles to the existing lines on the southern side of James Street, abutting on the Lower Marsh, and passing under Waterloo Station curves round to the right, under Cross Street and the South Eastern Railway viaduct, when it enters the York Road, and still curving to the right, passes under Stamford Street until Hatfield Street is reached. Here it bends to the left on a five-chain curve, and passing under some property at a depth of 56 feet reaches the Surrey side of the river at a point some 500 feet on the up-stream side of Blackfriars Bridge. The river is crossed obliquely, the centre line on the Middlesex side being about 120 feet on the up-stream side of Blackfriars Bridge. From this point the railway bends on a nine-chain curve to the right, and then passes along the centre of Queen Victoria Street to its terminus opposite the Mansion House. The total length of the line will be 1 mile 4 furlongs, 6·8 chains, or in round figures, 1½ mile. There are two separate tunnels running parallel to each other, one for the up and the other for the down traffic. They are circular in section and 12 feet internal diameter. The gradients of both lines beneath the Thames are only 1 in 800, whilst under Stamford Street the up-line has a gradient of 1 in 120, and the down line a gradient of 1 in 60. Along Queen Victoria Street the gradient is 1 in 88, falling to 1 in 100. From near Hatfield Street to the city both the tunnels will be in the London clay, but from that point towards Waterloo ballast will be encountered. This latter portion of the line will be constructed under compressed air, as large volumes of water will be met with in the ballast. The contract for the construction of the line from Cross Street to the city terminus was let to Messrs. Mowlem and Co., early in June 1894, and they at once began operations by constructing the stage now so conspicuous an object in the river near Blackfriars Bridge. Here two cast-iron cylindrical shafts were sunk to a point 40 feet below T.H.W.M., one above each of the tunnels, and below this the shafts were continued by underpinning in brickwork. The shields were then lowered in pieces, put together, and driven forward. Already 1600 feet of the up, or westernmost tunnel, and 1400 feet of the down, or easternmost tunnel, have been completed. Both tunnels are now under the Victoria Embankment, and are approaching the Metropolitan District Railway, under which there is a considerable depth of ballast, and a small cover of clay over the new tunnels. The Metropolitan District Railway Company required this company to drive the tunnels when passing under, and within 30 yards of their railway, under compressed air, and this is now in progress. The down tunnel towards Waterloo is approaching water-bearing strata, and here also the work is being carried on under compressed air. The ordinary rate of progress forward is 10 feet per day of twenty hours, the men working in double shift and the tunnels being practically finished with the exception of concreting the road portion as they proceed. The haulage of materials to and from the shafts is done by electric locomotives (one in each tunnel), designed and constructed by Messrs. Siemens Brothers and Co. The engines and dynamos for the electric lighting of the tunnels have been designed and constructed by Messrs. Patterson and Cooper, of Westminster. The engineers for the railway are Messrs. W. R. Galbraith and J. H. Greathead;

and their resident engineer is Mr. H. Dalrymple Hay; while Messrs. John Mowlem and Co. are represented on the works by Mr. William Rowell.

THE CITY OF LONDON BREWERY.

The City of London Brewery, which is situate in Thames Street, near London Bridge, dates back to 1580, when a "Brew-House" was established on part of the site by one Potts. In those days customers brought their own malt, &c., to be converted into beer or ale. The buildings and yards cover about 2 acres. Entering by the main gate, leaving the counting house on the left, are stables with stalls for over fifty horses; next comes the fining house where isinglass is dissolved to be used for clarifying ales. The engine house adjoins, containing a boiler and a 30 horse-power Boulton and Watt beam engine, which was erected in the beginning of the century. The engine has a 22-inch cylinder and a 6-feet stroke and uses 10-lb. steam. It continues to do satisfactory work in pumping water and driving part of the machinery. Between the wheel pit and the boiler is the entrance to the artesian well which supplies most of the water for brewing. There is a shallow or land spring well a few yards south, giving a valuable supply for refrigerating, &c. The Mill Loft, containing a large stock of malt, is a very old brick building, with massive timbers supporting the bins. Some old square shafting is still running in this department, which most likely dates back to horse-power time. Lifting tackle with an Archimedean screw in connection raises the malt from the barges and distributes it where required. A portion of the Mill Loft has been separated and another floor added, to receive a Billings converter, which is the latest addition to the plant. Adjoining the converter-room is the west brewery mashing stage, containing three mash tuns and two coppers. The cooler is on the top floor of the west wing, connected with four refrigerators, which command the nineteen fermenting vessels in the waterside tun-room, a building of three floors, forming the south front of the Brewery which was finished in 1884. Adjacent is the boiler house, containing four boilers, with heating tanks over and at the side. Proceeding northwards through Cooperage Yard, the east brewery mashing stage is reached, where there are two mash tuns, two coppers, and a 30 horse-power engine. Adjoining are the fermenting and cleansing rooms, the latter being fitted with slate vessels. East of this is Red Bull Yard, where are stables, farriers' and coopers' shops; south of the latter is the east wing, which is used as stores for hops, &c., and is connected with the stages by a tramway over the roofs.

THE DOVER OUTER HARBOUR EXTENSION WORKS.

Upon the occasion of this visit the members were conducted over the works by Mr. J. C. Coode, of Coode, Son and Matthews, the engineers, and Sir John Jackson, the contractor. Previously to the inspection the visitors were entertained at luncheon at the Grand Hotel, at which several of the members of the Harbour Board were also present.

The outer harbour, now under construction, has been designed for commercial purposes, and not as a harbour of refuge, the chief object being the provision, in all states of weather and tide, of accommodation for the embarking and landing of passengers on and from 'cross channel steamers. The powers for the construction of the harbour were obtained by the Dover Harbour Board in 1891. The works contemplated under the act consist of:—(*a*) An extension of the Admiralty Pier, 580 feet in length, running approximately in an easterly direction. (*b*) An eastern arm starting near the Clock Tower; total length, 2760 feet, and (*c*) The reclamation of about 5 acres of the sea-bed, between the shore end of the Admiralty Pier and the entrance to the existing inner harbour, with two large steamer jetties projecting therefrom. The work now under construction, as a first instalment of the complete design, is the east pier (*b*). The first 1260 feet of this work will be an iron viaduct in bays of 40 feet, except at three points in its length where stiffening bays of 20-feet span and of greater width will be added to give lateral rigidity to the work. The main part of the viaduct will have a uniform width of 30 feet, including a footpath 6 feet wide on each side. The deck is at a level of 19 feet above high water of spring tides.

In consequence of great irregularity in the quality of the chalk bottom, the centre pile of each bay is fixed on a cast-iron cylinder, filled with concrete, after being sunk well into the solid chalk; the outer piles have cast-steel screws 4 feet in diameter. The superstructure is formed of three rows of lattice girders, properly braced, carrying corrugated decking, on which the road and footpaths will be formed. The gutters, curbs and nosings are of cast-iron. The direction of the viaduct is approximately south-east. Its outer end will abut on the solid portion of the pier, this latter being 1500 feet long. For about 400 feet from its commencement, the solid work will follow the same south-easterly direction as the viaduct, but thereafter it will gradually curve to the south and south-west. The entrance between the head of the East Pier and the end of the Admiralty

Pier extension will be 450 feet in width, its aspect being slightly to the north of east. The blocks in this solid work will range from 12 to 20 tons in weight. Above low water they will be faced with granite, and will in all cases be founded on the chalk, into which they will be sunk a depth of about 3 feet. The top width of the pier will be 35 feet, and the coping level 10 feet above high-water spring tides, the difference between the level of this portion of the work and that of the viaduct being met by an incline with an easy gradient. On the seaward side there will be a parapet 10 feet wide, somewhat similar to that on the Admiralty Pier. The pier will be finished by a circular head, 55 feet in diameter, on which it is proposed to construct a lighthouse. The extension of the Admiralty Pier will be of a similar character of construction to the outer portion of the existing work, but it is proposed to use concrete blocks of greater weight than those in the present structure. As soon as sufficient shelter is obtained from works (*a*) and (*b*), it is proposed to commence the reclamation (*c*) and the two steamer jetties, each 400 feet long and 100 feet in width. These jetties will be furnished with landing stages, and will practically form covered stations into which the trains of the London, Chatham and Dover and the South Eastern railways will run. The bed of the harbour will be dredged so as to give a minimum depth of 15 feet at low water of ordinary spring tides alongside the jetties and in their vicinity. The sheltered area of the new harbour, when completed, will be 56 acres.

The Admiralty Pier and Inner Harbour.

The Admiralty Pier affords protection to the western side of the new works. There are two basins: one known as the Wellington basin, of about 3½ acres, with gates of 70 feet opening; and the other, the Granville basin, of 4¾ acres, with gates of 65 feet opening. The present outer harbour of 13½ acres will become an inner tidal harbour on the completion of the extension works. A new lighthouse, with a masonry tower surmounted by a lantern of the fourth order, is being erected at the turret end of the Admiralty Pier, and the slipway at the upper end of the Wellington basin is capable of hauling up a safe load of 800 tons. The river Dour, from which Dover takes its name, discharges into the harbour upon the upper or north side of the Wellington dock. Mr. A. T. Walmisley, M.Inst.C.E., as Engineer to the Dover Harbour Board, has charge of the Admiralty pier and inner harbour. Captain Dixon is the harbour master.

The Dover Electricity Supply Co.'s Station.

The entrance to the electric lighting station is by a private road leading from Park Street. The building consists of offices, occupying the west portion, and adjoining these are the engine and boiler rooms. The engine room, which is faced with glazed bricks throughout, is 100 feet in length by 30 feet in width; the boiler room is 100 feet long by 45 feet wide. The engine room contains the main engines and dynamos, which at present are two 100 K.W., one 75 K.W., and one 50 K.W. Mordey alternators, each coupled direct, through a flexible coupling, to Raworth vertical compound condensing engines, in which forced lubrication is adopted. The alternator bearings are lubricated by means of force pumps. Each main generating unit is controlled by a switch pillar containing, besides the necessary voltmeters and ammeters, the armature, field and synchroniser switches, which are interlocking. These switch pillars throw the alternators on to the omnibus mains which run to the circuit board through the recording and other instruments. There is at present provision on this circuit board for six circuits, two of which are for the control of public arc lamps, the remainder being for private lighting. Each circuit is provided with double pole quick-break switches, fuses and ammeter.

Situated on one side of the engine room are two continuous current dynamos, coupled direct to vertical compound tandem engines. These machines feed on to omnibus mains from which the alternator fields are excited. The engine room also contains two Tangye centrifugal pumps, coupled direct to vertical engines, which draw water from the river Dour at a point about 100 yards distant, for use in the condensers, attached one to each of the main engines. The pumps draw their supply through two 12-inch pipes, forming a duplicate suction, and also discharge into duplicate 12-inch mains. A basin has been built in the river bed at a point where the suction pipes draw their supply. All the engines are supplied with steam from a ring main, situated in the boiler room and drained by a McDougall steam trap. The floor of the engine room is about 5 feet above the level of the road. Machinery can thus be readily lifted from waggons by means of a 15-ton crane which traverses the engine room.

The boiler room, which is on the road level, now contains two Babcock and Wilcox boilers, each of 200 horse-power, working at 150 lb. pressure, with space and foundations for five more of the same size. The flue extends along one side of the boiler room, passes under the front of the buildings, and terminates in a handsome circular chimney shaft, 120 feet in height. A Green's economiser, of 128 tubes, the scrapers of which are driven by an alternating current motor, is employed for heating the feed-water, which is drawn by two 3-throw feed-pumps, either from a well sunk in the boiler room, or from the tank receiving the condensed water from the main engines, and which can be further heated by the exhaust steam from the auxiliary engines. The feed-pipes are also arranged so that these pumps can deliver water direct into the boilers without its passing through the economiser. The boiler room also contains a water meter and a measuring tank. The engine and boiler rooms are lighted and ventilated from the roof, so as to avoid side windows, thus reducing any sounds to a minimum. The supply leaves the station at a pressure of 2000 volts, by Silvertown concentric cables, to some eighteen transformer street boxes in various parts of the town, where the current is converted to a pressure of 100 volts and distributed by means of Prescot paper-insulated mains to consumers' premises. There are at present twenty-one public arc lamps in the streets, each of 2000 N.C.P., and ten more lamps have been contracted for, to be suspended from arches. The contract for the whole of the machinery is being carried out by the Brush Electrical Engineering Company, Limited; the engineer and manager is Mr. A. J. Lawson, and the resident engineer Mr. A. A. Whitlock. Sir William Crundall, the Mayor of Dover, and chairman of the Electricity Supply Company, conducted the visitors over the Station, and afterwards entertained them at afternoon tea in the Town Hall.

THE SCHOOL OF GUNNERY, SHOEBURYNESS.

Upon visiting the School of Gunnery and the new Experimental Ranges at Shoeburyness, the members were received, in the absence of the Commandant, by Lieut.-Colonel Bally, R.A., Lieut.-Colonel Howard, R.A., Major Elmslie, R.A., Major Inglefield, R.A., and Captain Nicolls, R.A., by whom they were conducted over the various works, and who explained the details of the operations. The first part of the visit consisted of an inspection of the guns, elevating and training gear, and apparatus belonging to the instructional portion of the school. The members were then entertained at luncheon at the Royal Artillery Mess, and were afterwards conveyed by train to the new Experimental Ranges, situate about two miles distant from the School of Gunnery, where a special programme of practice was carried out. Ten rounds were first fired from a 6-inch breech-loading gun on a disappearing mounting on the spring storage system, the force of the recoil being made to store up power for the next elevation. The charge was 48 lb. of E.X.E. powder, with 100 lb. common and Palliser shell, the muzzle velocity being 1960 foot-seconds. A 12-pounder Elswick quick-firing gun was then fired with a charge of 1 lb. 10 oz. of cordite and a 12½-lb. common shell, the muzzle velocity being 2200 foot-seconds. A number of rounds from 3- and 6-pounder Hotchkiss quick-firing guns were then fired at $\frac{3}{16}$ inch steel plates, representing torpedo boats, with good execution. The 3-pounder gun fired a charge of $6\frac{6}{16}$ oz. of cordite and a steel shell, the muzzle velocity being 1873 foot-seconds. The charge of the 6-pounder gun was 7¾ oz. of cordite and a steel shell, the muzzle velocity being 1818 foot-seconds.

The next experiment was a trial of armour-piercing shot against a compound armour plate. The plate measured 5 feet by 5 feet by 16 inches thick, and was composed of a 3½-inch steel face on 12½ inches of wrought iron, with a backing of 4 feet of oak. It was held in Lieutenant Warburton's frame, and the range was 237 feet. The gun was a 10-inch breech-loader, firing a charge of 252 lb. of prism brown powder with a 500-lb. armour-piercing shot, the muzzle velocity being 2040 foot-seconds. To have been the victor the shot should have passed through the plate, but it did not, although it severely punished it. The point of the projectile was embedded in the plate, which was badly fractured, and about 15 inches of the rear part of the shot lay on the ground in front of the plate, which thus effectually kept the shot out. The striking velocity was 2009 foot-seconds. The visitors were then conducted to the hydraulic gantry, which was successfully worked, a 12-inch 46-ton gun being lifted and traversed by it with ease and accuracy. The pressure is 700 lb. per square inch, and the traverser will lift 130 tons. After inspecting a variety of guns and well-punished armour-plates, torpedo boats, and other targets, the visitors witnessed some practice from 3- and 6-pounder quick-firing guns against a rapid running target representing a torpedo boat in motion broadside on. Another target, representing a torpedo boat advancing towards the battery at full speed, was also fired at; and on these targets being brought ashore, they showed that the guns had done good work. Altogether, the visit proved highly instructive and interesting.

October 7th, 1895.

WILLIAM G. PEIRCE, PRESIDENT, IN THE CHAIR.

THE RELATIVE VALUE OF PERCOLATION GAUGES.*

BY REGINALD EMPSON MIDDLETON.

IN the course of his investigations, on behalf of the Royal Commission on Metropolitan Water Supply, into the alleged depletion of the rivers, springs and wells in Hertfordshire, the author found it necessary to compare the records of the percolation gauges, to which reference was made by Dr. John Hopkinson, F.G.S., one of the witnesses for the Hertfordshire County Council, with the tables of rainfall supplied by the same witness, and to endeavour to discover internal and external evidence of the relative reliability, or otherwise, of the several records. If it be assumed that the records of rainfall are accurate—and there is no reason for doubting their substantial accuracy—what reliance is to be placed on the relative value of the records of percolation, and is there internal or external evidence to support them? This was the question to be answered.

Four percolation gauges are referred to by Dr. Hopkinson, namely, two at Nash Mills, one at Lea Bridge, and one at Rothamsted. The first gauge, at Nash Mills, is described as composed of three feet of chalk, with grass growing on the surface. The period of observation extends from April 1st, 1854, to March 31st, 1884. The second gauge, also at Nash Mills, is said to be made with three feet of soil, with grass growing on the surface. The period of observation extends from April 1st, 1842, to March 31st, 1884. The third gauge, at Lea Bridge, is described as being made with three feet of soil, with grass growing on the surface, and the period of observation extends from April 1st, 1852, to March 31st, 1873. Through the kindness of Mr. W. B. Bryan, the engineer to the East London Water Company, the author has also had access to the records of percolation at Lea Bridge and Old Ford for the years 1875 to 1890. The fourth gauge, at Rothamsted, is stated to be made with five feet of soil, the surface being kept free from vegetation. The period of observation extends from April 1st, 1871, to March 31st, 1892.

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* The President's Gold Medal was awarded to the author for this paper.

The average quantity of rain which percolated through the several gauges during the summer months, from April 1st to September 30th, of the years from 1854 to 1883, being those which are most fully comparable, was 2·19 inches, 0·84 inches, 1·13 inches, and 3·19 inches respectively; the ratios to the general average of 1·84 inches being 119, 46, 61 and 173. For the winter months, from October 1st to March 31st, for the same years, the average percolation in the four gauges was 8·43 inches, 5·75 inches, 6·26 inches, and 8·62 inches, and the ratios to the general average of 7·27 inches are 116, 79, 86 and 118. The yearly percolation of the several gauges is for the same period 10·62 inches, 6·59 inches, 7·39 inches, and 11·81 inches, and their ratios to the general average of 9·10 inches are 117, 72, 81 and 130.

From these figures it is seen that a gauge made with chalk three feet thick, and with grass growing on the surface, discharges from 58 per cent. to 73 per cent. more water on the average during the summer months than do similar gauges filled with soil, and 54 per cent. less than where the gauge is five feet thick, made with soil, but without grass. During the winter months the conditions are much altered; from 30 per cent. to 37 per cent. more water percolates through the chalk gauge than finds its way through the soil gauges with vegetation growing on them, while the soil gauge, without vegetation growing on it, and the chalk gauge allow equal quantities of rain to pass through them.

The second and third gauges, which are both of them made with three feet of soil, with grass growing on the surface, should be strictly comparable for the years of their co-existence, namely, between the years 1852 to 1873 and 1875 to 1883, yet the average summer percolation in the first-named gauge is at the rate of 0·85 inches of rain, while in the second it is 1·14 inches, or 34 per cent. higher, and the average winter percolation amounts to 6·05 inches in the first gauge and to 6·39 inches in the other, so that the winter record of the Lea Bridge gauge is 5 per cent. higher than that for the similar gauge at Nash Mills. A comparison made year by year shows that this difference cannot be accounted for by some unrecognised dissimilarity between the gauges, which causes one to maintain a uniformly higher record than the other.

The table No. V. and the diagram which accompanies this paper clearly show that such is not the case, that the discrepancies cannot be referred to this cause, nor have they any reference to the altered conditions of rainfall in the two places, which, instead of making the approximation closer, has the contrary effect, the rainfall at Lea Bridge being for the years 1860 to 1883, the total length of the record, as 25·91 inches to 28·64 inches, or 10½ per cent. less than that at Nash Mills.

If, again, the first eleven years of these records be compared with the second ten years, it is found that the yearly percolation in the Nash Mills gauge is at the rate of 6·67 inches and in the Lea Bridge gauge 6·16 inches, while for the second period, from 1863 to 1873, the figures are 5·55 inches and 7·76 inches respectively, so that the large discrepancy is found to be in the second period. If, again, the percentages of rainfall be examined on a like basis, that is to say, for the periods from 1860 to 1866, and from 1866 to 1873, it is found that the Nash Mills gauge passed, during the former period, 23 per cent. of the rainfall, and that at Lea Bridge 29 per cent., while in the second period, the quantity of rain passed by the Nash Mills gauge was 19 per cent. and from the Lea Bridge gauge 29 per cent.

It is shown by these figures that there are remarkable discrepancies between these two gauges, and it appears as if the Nash Mills gauge had, for some reason which is not obvious, got into a condition which caused it to discharge a less percentage for the later years than for the former ones, up to the year 1872–3, when it returned to something more than its former activity, and it is found that during the eight years, from 1875 to 1883, the percolation at Nash Mills was at the rate of 8·92 inches of rain, while at Lea Bridge it was at the rate of 8·58 inches, and the positions of the gauges had to some extent become reversed, so far as the quantity percolating is concerned. When measured in percentages of rainfall, however, Lea Bridge is still found to discharge the larger percentage of 35 per cent., as against 31 per cent. at Nash Mills.

If the year 1872–73 be eliminated from the record, the discrepancy becomes still more marked, as under these circumstances the average percentage of rain passed by the Nash Mills gauge becomes only 16 per cent., while that at Lea Bridge is 28 per cent., or nearly double. The difference between the gauges becomes marked after 1864, and from that date up to 1873 there is no year in which the percolation at Lea Bridge is not largely in excess of that at Nash Mills. Taken in three-year periods, it appears that the difference between the gauges becomes most marked after 1864, and that from that date up to 1873 there is no period in which the percolation at Lea Bridge is not largely in excess of that at Nash Mills.

Although the other two gauges, being of different construction from those already considered, are not directly comparable with them, yet, when reduced to the basis of ratios to the average, the whole of them should be comparable. But, when considered on this basis, they are no more corroborative of one another than are the two instanced above, although they are directly comparable. If the two gauges at Nash Mills be compared in the same manner as the soil gauges at Nash Mills and Lea Bridge, in five-year periods, so as to eliminate merely local and accidental differences, so far as is possible, the average percolation assumed in both cases being taken at 7 inches, in order to assimilate the figures with those in the former tables, the results are as follows:—

TABLE I.

Period.	Nash Mills chalk gauge, ratios in five-year periods.	Nash Mills soil gauge, ratios in five-year periods.	Nash Mills chalk gauge, percentage of rainfall.	Nash Mills soil gauge, percentage of rainfall.	Ratio for fifteen years, Nash Mills chalk gauge, percentage of rainfall.	Ratio for fifteen years, Nash Mills soil gauge, percentage of rainfall.	Rainfall.
1854–59	80	72	22	19	..	..	25·88
1859–64	98	116	27	32	..	..	25·58
1864–69	81	86	21	22	23	24	27·64
1869–74	93	77	25	21	..	..	25·74
1874–79	129	124	28	26	..	..	32·91
1879–83	123	132	28	29	27	25	31·35

These figures show a similar result to that obtained from the former tables, the percentage of rainfall for the Nash Mills soil gauge is in excess of the chalk gauge for the years 1854 to 1869, but is below the latter gauge for the years 1869 to 1883. In order to complete the comparison, the Nash Mills soil gauge and the Rothamsted gauge should be examined in the same way for the years 1871 to 1883, being those of their co-existence.—

TABLE II.

Period.	Nash Mills chalk gauge, ratios in four-year periods.	Nash Mills soil gauge, ratios in four-year periods.	Rothamsted soil gauge, ratios in four-year periods.	Nash Mills chalk gauge, percentage of rainfall,	Nash Mills soil gauge, percentage of rainfall,	Rothamsted soil gauge, percentage of rainfall.	Rainfall, Nash Mills.	Rainfall, Rothamsted.
1871–75	100	87	72	27	23	18	26·21	27·76
1875–79	140	139	158	29	28	30	34·46	36·32
1879–83	123	132	131	27	29	29	31·35	32·00
				28	27	26		

In this instance it appears that the records of the Rothamsted gauge for the first four years of its existence are unreliable and are too low, and there is other evidence which tends to prove the same thing, otherwise the two gauges, when the records are averaged over periods of four years, are found to be fairly in agreement. Perhaps the most remarkable evidence of discrepancy is to be found in a comparison of the gauges at Lea Bridge and Old Ford, for these gauges are situated only some 2½ miles apart. They are presumably exactly similar in construction, yet the differences, both as regards the percentage of rainfall which percolated and the rainfall itself, as shown in Table No. VI. are remarkable.

Thus the percolation at Old Ford measured in percentages of rain was 17·1 per cent. less than that at Lea Bridge, and in the year 1886 it was 61·8 per cent. less. Also, during the summer of 1879, 7·07 inches percolated at Lea Bridge, while only 5·77 inches passed through the gauge at Old Ford, the percentages of rain being 34·6 per cent. and 24·7 per cent. respectively.

The three driest years, according to the Nash Mills chalk gauge, are those from 1862–65, with an average of 49 per cent. In the Nash Mills soil gauge the same years give the lowest record, with an average of 53 per cent. In the Lea Bridge gauge the three driest years are those from 1853 to 1856, with an average of 42 per cent., while if the average of these three gauges be taken, the resulting figure is 60 per cent. for the years 1862–65, and this figure may, it is thought, be accepted as correct, especially as the result agrees closely with that which has been used for years to determine the probable least rainfall for the three driest consecutive years. Sixty per cent. of the average percolation represents 5·46 inches of rainfall, and this may therefore be taken as the smallest quantity which is likely to percolate, on the average, of the three driest years.

In two-year periods, the lowest ratios are found to be, on No. 1 gauge, 46·5 per cent. for the years 1863 to 1865. On No. 2 gauge 46 per cent. for the years 1873 to 1875 and 49 per cent. for the years 1857 to 1859, and on No. 3 gauge the years 1853 to 1855 give the lowest record with 23 per cent., the record for the years 1857 to 1859 and 1863 to 1865 being 59 per cent. and 78 per cent. respectively, and the lowest probable percolation is 45 per cent. or 4·10 inches of rain. In single years, the lowest ratios are 33 per cent. on No. 1 gauge, 1 per cent. on No. 2 gauge, and 20 per cent. on No. 3 gauge, but these are for different years, and the lowest average figure obtainable is 29 per cent. in 1858–59, the next lowest being 37 per cent. in 1873–74. The latter figure is probably the more reliable one, as the former is greatly affected by the abnormally low percolation on the Nash Mills soil gauge of 1 per cent., which is not supported by either of the other contemporary gauges. Thirty-seven per cent. of the average percolation is 3·37 inches of rain, which may be taken as the smallest probable percolation during one year. The average percolation referred to above is that deduced from the average of the four gauges, and amounts to 9·10 inches of rain.

A large amount of evidence was given before the Royal Commission to show that the amount of percolation is at least 10 inches, and probably exceeds this amount, but the author has preferred to take the actual gaugings as the basis of his calculations, although he also is of opinion, as an opinion only, that the quantity so recorded is underestimated, and indeed in the figures used, if more weight be given to the Rothamsted gauge, and less to the Nash Mills gauges, and the average be carried forward to the year 1891, instead of terminating in 1883, it is raised from 9·10 inches to 9·46 inches.

In order to estimate the value of each gauge with reference to the district, it is necessary to remember that the latter is not uniformly covered with chalk, soil, or vegetation, part is almost bare chalk, part is arable and is covered with bare soil, another portion is covered with vegetation, while yet another, although almost impermeable in itself, passes the water which flows from its surface into swallow holes, or on to land of a highly permeable character, whence it sinks into the chalk basin beneath more rapidly and in greater volume than if it had fallen directly on to bare chalk, where the influences of evaporation would have greater effect on account of the greater area affected in a given time.

Under these circumstances and considering that much land which is cropped in summer, when the amount of percolation is small, is bare in winter, when the percolation is large, and that other districts send the larger proportion of their flood water into the chalk basin almost unaffected by evaporation, it is thought to be an error on the safe side to give the soil gauges with vegetation growing on them twice the weight, in striking the average, which is given to the chalk gauge and the soil gauge without vegetation, and that the average percolation so arrived at of 9·10 inches of rain is probably an under estimate. If equal weight be given to each class of gauge, that is to say, if the two soil gauges with vegetation be treated as one, the average becomes 9·81 inches.

In looking for evidence to confirm the general conclusions arrived at from the percolation gauges, the records being in themselves very contradictory, except in so far as they show general rises and falls, the most natural direction in which to search for such confirmation is in the gauging of the rivers. A very cursory examination of these data will, however, show that much direct assistance cannot be obtained from them. The only river in the district which has been gauged is the Lea; these gaugings are not continuous, and many of the years from which the best comparisons might be drawn are missing. The gaugings themselves, although they have a superficial likeness to the records of percolation, are not in fact directly comparable with them, because they comprise two elements, namely, spring water and flood water, and it is necessary to separate the two, before results, which have any real bearing on the question of percolation, can be obtained, and this is the more necessary because the time when the springs are at their highest is one of only moderate flood water, while the period of lowest springs precedes, by a month or so, that of the highest floods. On the average of years the wells are, so far as the evidence goes, at their highest in April, and at their lowest in November.

An examination of the gaugings of the river Lea points to the volume of water passing down that river, which is derived from underground sources alone, as not exceeding 6700 cubic feet per minute, or 60,000,000 gallons a day on the average of years, and it is evident that it has frequently been less than this amount. If this view be correct, the supply being greatest in April and least in November, the following figures may be taken as an approximation to the monthly average supplies from this source:—

	Cub. ft. per min.		Cub. ft. per min,
January	5,800	July	7,100
February	6,000	August	6,300
March	7,800	September	5,600
April	9,000	October	5,000
May	8,300	November	4,500
June	7,600	December	5,500

Deducting these figures from the monthly totals for twenty years of gaugings the remainder is the storm water, and the ratio which it bears to the monthly rainfall can be calculated, and the results are as follows —

	Rain, inches, or per cent. of rainfall.	
January	0·81	37·7
February	0·75	47·7
March	0·51	30·9
April	0·25	15·6
May	0·24	11·6
June	0·12	6·6
July	0·11	4·8
August	0·09	3·9
September	0·11	5·2
October	0·27	10·0
November	0·63	22·4
December	0·69	33·3
Average	0·38	19·1
Total	4·58	18·2

Dividing the year into two periods, the summer discharge is found to be equal to 0·92 inches of rain, or 7·9 per cent. of the rainfall. In the winter months 3·66 inches of rain, equal to 30·3 per cent. of the average rainfall, finds its way into the river as storm water.

If this be true for the storm water, the percolation should follow similar, or nearly similar, laws, and the summer percolation should be to the winter as 0·92 is to 3·66. If the percolation be taken at 9·10 inches on the average, the percolation for each month will be, to correspond with the figures already given for storm water, as follows:

	Rain, ins.		Rain, ins.
January	1·61	July	0·22
February	1·49	August	0·18
March	1·01	September	0·22
April	0·50	October	0·54
May	0·48	November	1·25
June	0·23	December	1·37

The percolation for summer months is found to be 1·82 inches, and for the winter months 7·27 inches, and these figures correspond almost exactly with the average percolation for the years 1854 to 1884, as deduced from the percolation gauges.

It appears that during dry, sunny years there is practically no storm water passing into the river, and that the whole of the water found there comes from underground supplies. The minimum quantity gauged was in the year 1874, and amounts on the average of the six summer months to 5641 cubic feet per minute, or to 3·02 inches of rain per annum, or 0·25 inches per month; but if all the months, 84 in number, which are little affected by storm water, be considered, the average flow of the river is only 7758 cubic feet per minute, or 4·17 inches of rain per annum. As a certain quantity of storm water was present during some of the years instanced, and as the summer level in wells is considerably higher on the average than the winter level, the author considers that in taking the average flow of the river due to underground water at 6666 cubic feet per minute, he has, if anything, erred on the side of liberality, and that the actual quantity is less than this amount. The above figure includes the quantity available from the valley of the Stort, and the amount which comes from the chalk basin is estimated at 5751 cubic feet per minute, or 3·70 inches of rain per annum on an area of 351 square miles, the area of the chalk basin above Feilde's Weir.

It has been shown, however, that the average percolation is, if the percolation gauges be relied on, 9·10 inches, while there is a large consensus of opinion that it is greater than this. What, then, becomes of the difference of 5·40 inches of rainfall, or 8393 cubic feet per minute, or 75,000,000 gallons daily? Either the effect of percolation is very greatly over-estimated, or a large proportion of the underground water, does not find its way into the visible river, but has some other outlet, and is still available for water-supply purposes.

An examination of the Thames gaugings, although the period is not co-extensive, being from 1883 to 1893, shows what is practically an identical result; the percolation figures for the summer and winter periods, as deduced from a comparison with the storm water, being practically the same, and the ratios of discharge for the different months disagreeing to a very small extent.

The figures are as follows:

TABLE III.

—	Rain discharged by River Thames in inches of rain over whole area.	Ratio to Average.	Rain discharged by Lea in inches of rain over whole area.	Ratio of Average.
January	1·06	303	0·81	213
February	1·26	242	0·75	198
March	0·77	148	0·51	134
April	0·43	82	0·25	66
May	0·30	57	0·24	63
June	0·16	30	0·12	32
July	0·10	20	0·11	29
August	0·09	17	0·09	23
September	0·09	17	0·11	29
October	0·36	69	0·27	71
November	0·75	143	0·63	165
December	0·89	171	0·69	181
Total	6·27	..	4·58	..

In the case of the Thames, the deduction made for water supplied from underground sources has been taken at 400,000,000 gallons a day on the average, and the figures given above serve to confirm the view that this figure approximates closely with the actual quantity of water derived from this source.

The permeable area of the watershed, as defined by Mr. Topley, measures 2032 square miles, the mixed strata 438 square miles, and the impermeable 1454 square miles. If percolation at the rate of 10 inches of rain be allowed for on the permeable area, 7 inches on the mixed, and 3 inches on the impermeable for gravel, &c., the quantity of rain collected should equal a daily supply at the rate of 1,097,000,000 gallons in round numbers; but only 400,000,000 gallons are accounted for as passing Teddington Weir. What, then, becomes of the difference? It can only be concluded that, as in the case of the Lea, the percolation is enormously over-estimated, or that the underground supply has another outlet, and that 697,000,000 gallons daily are available for purposes of water supply without injury to the river.

To return to the calculations resulting from the gaugings of the Rivers Thames and Lea. If the ratios to the average for the different months be compared with the monthly records of percolation at Lea Bridge for the years 1862 to 1873 (see 'Minutes of Proceedings, Inst. C.E.,' vol. xlv.), notwithstanding that the periods examined, owing to the difficulty of obtaining more complete records, are not at all the same, there is a fairly close correspondence, and it is clear that the gaugings of storm water do afford corroborative evidence as to the ratio of percolation. Were it possible to determine the quantity of spring water in the river during each month of each year, or even for each month on an average of years, with greater accuracy, the approximation would be closer than it is.

TABLE IV.

—	Ratio to the average in the gaugings of storm water in the River Lea for 20 years.	Ratio to the average in the gaugings of storm water in the River Thames for the years 1883 to 1893.	Ratio to the average in the percolation gauge at Lea Bridge for years 1862 to 1873 and 1875 to 1891.
January	213	203	246
February	198	242	166
March	134	148	103
April	66	82	49
May	63	57	40
June	32	30	29
July	29	20	16
August	23	16	30
September	29	17	10
October	71	69	76
November	165	143	129
December	181	171	204
Summer	40	37	29
Winter	160	163	154

There is yet another source from which evidence of the relative value of percolation gaugings may be obtained, namely, that of well sections. Two sections have been examined—namely, that of a well at Barley, near Royston, the record of which extends, with one short break, from 1864 to 1891, and the greater portion of which is to be found in the Transactions of the Hertfordshire Natural History Society; the other is that of the Cow Roast well, the property of the Grand Junction Canal Company, and gives monthly records of level from 1851 to 1890. For the earlier records the author has to thank Mr. R. H. Twigg, M. Inst. C.E., while those of a later period have been given me by the courtesy of the Canal Company.

Table V.

Comparative Table, showing the Percolation of the Nash Mills and Lea Bridge Soil Gauges, and the percentage of Rainfall which percolated, in yearly and three-year periods.

Nash Mills and Lea Bridge Soil Gauges.					Yearly percentage of rain percolating at Nash Mills.	Yearly percentage of rain percolating at Lea Bridge.	Percentage of rain percolating at Nash Mills soil gauge in 3-year periods.	Percentage of rain percolating at Lea Bridge soil gauge in 3-year periods.
Periods.	Summer percolation at Nash Mills.	Summer percolation at Lea Bridge.	Winter percolation at Nash Mills.	Winter percolation at Lea Bridge.				
1852–53	0·24	2·00	10·74	8·87	..	..	..	..
1853–54	..	..	4·22	2·00	..	..	..	..
1854–55	0·19	0·03	2·45	1·42	..	..	..	..
1855–56	2·79	0·14	6·82	5·72	..	..	..	..
1856–57	1·11	1·92	3·73	3·59	..	..	..	..
1857–58	0·80	1·40	5·64	5·78	..	..	..	..
1858–59	..	0·60	0·09	0·90	..	..	..	..
1859–60	3·16	4·23	9·27	9·21	..	..	..	..
1860–61	1·13	0·16	7·61	6·12	31	24	..	..
1861–62	2·39	1·65	7·42	6·20	34	30	..	..
1862–63	..	..	3·56	5·85	12	22	26	25
1863–64	0·35	0·06	3·18	4·24	12	17	19	23
1864–65	..	0·86	3·42	6·33	12	28	12	23
1865–66	0·03	1·42	10·47	12·44	37	54	20	33
					— 23	— 29		
1866–67	0·18	0·09	4·64	7·87	17	31	22	38
1867–68	0·04	0·04	2·03	4·60	7	18	20	34
1868–69	0·02	0·16	7·64	8·59	27	34	17	28
1869–70	..	0·05	4·50	5·82	16	22	17	25
1870–71	..	0·45	2·08	7·71	7	31	17	29
1871–72	1·00	1·06	4·65	6·80	20	30	14	28
					— 16	— 28		
1872–73	..	..	11·25	9·04	39	35	22	31
					— 19	— 29		
1875–76	0·50	0·09	6·08	6·42	23	25	..	..
1876–77	1·04	1·56	10·13	10·13	39	45	..	..
1877–78	2·16	6·76	4·00	3·20	21	38	28	36
1878–79	6·94	7·10	5·75	7·94	44	58	35	47
1879–80	..	0·40	2·79	2·66	9	12	25	36
1880–81	..	..	13·59	11·08	47	43	33	38
1881–82	0·48	0·40	6·24	5·91	24	24	27	26
1882–83	..	0·33	11·67	8·86	41	35	37	34
Average	0·85	1·14	6·05	6·39	..	..	..	..

In the former well the fluctuations of level extend to 80 feet, while in the latter they do not exceed 20 feet. The highest level is arrived at, on an average of years, in April, and the lowest level is reached in November and as when the water level is high the water gradient is at its steepest, much more water must be passing through the strata at such times than when the level is lower and the gradient flatter.

A simple comparison of average water levels will not afford a true criterion of the quantity of water discharged into the river, and some means must be adopted for giving greater effect to high-water seasons than to low ones. In order to obtain this end the author has multiplied the levels by a coefficient, representing the flow of water at different gradients, followed by the levels; he acknowledges that this is a rough-and-ready way of arriving at the desired conclusion, and that it is probably inaccurate, but he has not been able to devise a better, and he therefore gives the figures of ratios derived from the well sections for what they are worth. So far as they go, they are generally confirmatory of the percolation records, and of those obtained from the river gaugings, and suggest the same periods of wet and drought.

TABLE VI.

Year.	Lea Bridge Percolation.	Old Ford Percolation.	Lea Bridge Yearly Percentage of Rain.	Old Ford Yearly Percentage of Rain.
	inches	inches		
1875	7·57	8·61	27·7	29·1
1876	7·12	8·43	27·8	27·9
1877	8·96	9·60	32·7	29·8
1878	10·74	9·90	34·0	28·7
1879	12·84	12·59	45·0	35·2
1880	9·25	14·61	36·0	43·5
1881	8·61	11·30	33·8	37·8
1882	6·47	6·43	26·0	21·0
1883	6·35	6·24	29·2	21·9
1884	3·13	4·41	19·0	17·5
1885	5·79	5·88	24·4	17·9
1886	9·23	6·07	45·0	17·2
1887	4·00	3·43	26·4	12·7
1888	8·24	8·19	29·6	23·5
1889	10·08	7·86	33·2	25·1
1890	3·87	6·11	18·1	23·8
Average ..	7·64	8·10	30·5	25·8

Above a certain level the Cow Roast well ceases to give an accurate record, as at this level the water overflows into the neighbouring stream. Since the year 1889, or thereabouts, the level of the water in this well has been affected by pumping from the wells of the Chiltern Hills Water Company, which are

TABLE VII.*

Period.	Ratios of Nash Mills Chalk Gauge.	Ratios of Nash Mills Soil Gauge.	Ratios of Lea Bridge Soil Gauge.	Ratios of Old Ford Soil Gauge.	Ratios of Rothamsted Soil Gauge.	Ratios of Barley Well.	Ratios of Cow Roast Well.	Ratios of Thames Gaugings of Storm Water.	Ratios of River Lea Gaugings of Storm Water.	Average Ratios of Percolation Gauges.	Average Ratios of Percolation Gauges in 3-year periods.	Average Ratios of Wells in 3-year periods.	Average Ratios of River Gaugings in 3-year periods.
1851–52	..	78	..	..	..	..	88	..	..	..	..	..	..
1852–53	..	167	147	..	..	..	163	..	..	157	..	..	..
1853–54	..	64	27	..	..	..	116	..	..	46	..	..	..
1854–55	54	40	20	..	..	..	48	..	..	36	80	109	..
1855–56	128	146	80	..	..	..	104	..	..	118	67	89	..
1856–57	80	73	74	..	..	..	104	..	..	76	77	85	..
1857–58	75	98	97	..	..	..	82	..	..	90	95	97	..
1858–59	65	1	20	..	..	..	46	..	..	29	65	77	..
1859–60	201	189	181	..	..	..	106	..	..	190	103	78	..
1860–61	81	133	85	..	..	..	116	..	..	100	106	89	..
1861–62	94	148	106	..	..	..	92	..	..	116	135	105	..
1862–63	53	54	80	..	..	..	94	..	..	62	93	101	..
1863–64	60	54	58	..	..	31	64	..	..	57	78	78	..
1864–65	33	52	97	..	..	31	24	..	..	61	60	61	..
1865–66	115	159	187	..	..	106	104	..	..	154	91	65	..
1866–67	79	73	108	..	..	122	123	..	..	87	101	90	..
1867–68	54	31	63	..	..	88	88	..	..	49	97	105	..
1868–69	124	116	118	..	..	96	115	..	..	119	85	105	..
1869–70	83	68	80	..	..	68	77	..	..	77	82	89	..
1870–71	67	31	110	..	..	36	63	..	..	70	89	76	..
1871–72	115	86	106	..	61	63	80	..	..	92	80	65	..
1872–73	151	171	122	..	103	121	127	..	..	137	100	82	..
1873–74	48	29	..	..	33	50	70	..	27	37	86	85	..
1874–75	85	63	..	..	91	38	80	..	42	80	85	81	..
1875–76	108	100	88	104	142	100	139	..	156	108	75	80	75
1876–77	126	170	158	173	155	124	141	..	214	156	115	104	138
1877–78	132	93	134	116	124	113	117	..	101	120	128	122	157
1878–79	196	193	203	175	213	177	152	..	..	196	157	137	..
1879–80	70	42	41	92	79	133	111	..	..	65	127	134	..
1880–81	126	207	149	202	154	170	152	..	..	168	143	149	..
1881–82	132	102	85	87	118	144	126	..	163	105	113	139	..
1882–83	165	177	124	114	174	170	126	..	250	151	141	148	..
1883–84	New Gauges		56	51	93	118	89	105	86	67	108	129	169
1884–85	100	75	55	62	119	53	66	66	50	82	100	104	135
1885–86	147	170	109	88	129	104	110	142	173	129	93	90	104
1886–87	119	132	73	48	100	..	107	126	102	94	102	91	110
1887–88	96	127	97	85	123	..	52	79	49	106	110	89	112
1888–89	145	142	146	106	126	88	81	132	128	133	111	81	103
1889–90	88	81	87	129	103	108	62	67	109	98	112	74	94
1890–91	88	82	..	..	82	35	..	32	32	84	105	68	83
1891–92	..	..	..	..	..	..	..	147	117	..	..	..	84
1892–93	..	..	..	..	..	..	..	101	122	..	..	..	92
Average inches of rain percolating from 1853 to 1883	10·62	6·58	7·39	7·74	11·81	..	..	..	..	9·10	..	..	..
Proportion to average rainfall	39%	24%	28%	29%	44%	..	..	..	..	34%	..	..	..

* This table is referred to on p. 166.

situated a short distance above the Cow Roast well, and in the same watershed, and they can no longer be relied on to afford the same ratios as formerly.

Table No. 7 represents the ratios of percolation to the average of each for the gauges at Nash Mills, Lea Bridge, Old Ford and Rothamsted; the averages of the above gauges, the ratios as deduced from the gaugings of the rivers Thames and Lea, and from the wells at Barley and Cow Roast, along with the same ratios in three-year periods.

The general conclusions arrived at are, that percolation gauges do afford a general indication of the amount of rainwater which passes into the subsoil under given conditions, but that the discrepancies between gauges are so marked that no one gauge can be relied on as an authoritative index of what has taken place in the whole of the district. For reasons which have already been referred to, a result obtained from the averages of all the gauges is more to be relied upon, as a record of the percolation in the district, than that of any particular gauge, and the gaugings of the rivers will, if they be examined in detail and reduced in the manner indicated in the tables, be found to give a truer record of the ratios of percolation with reference to an average to be fixed in some other manner, than can be deduced from the records of the percolation gauges, and such record refers to the whole drainage area of the river, and not to one particular spot or to three or four spots in that area only, and is therefore more reliable as a general index. If the tables be reduced with greater care than the author has been able to give to them, so as to decide what is the proportion of spring water passing down the river each month of each year, instead of using a figure which is deduced from the average of several years, the results obtained will be still more accurate, and will approximate still more closely to those deduced from the averaged records of the percolation gauges.

DISCUSSION.

The PRESIDENT said he had very great pleasure in moving a vote of thanks to Mr. Middleton for his most interesting paper. He (the President) had had some little experience in sinking in the earth for water, and his opinion was as regarded percolation that most of the water found in the chalk fissures came direct from rivers through those fissures, although a certain quantity must come through the sweating or bleeding of the chalk. The gaugings were certainly most interesting, especially when carried on over a large area and through a long series of years. Most of those who understood anything about searching for water in the earth would agree that the paper was deserving of very great praise.

The vote of thanks was accorded unanimously.

Sir JOHN EVANS, K.C.B., F.R.S., said that as one who, during the last fifty-five years, had paid considerable attention to percolation gauges, and had lived at Nash Mills during the whole of that time, he naturally took considerable interest in any discussion of the results of the gauges, which were originally instituted by his uncle, Mr. Dickinson, and had since been carried on by himself, and subsequently by the firm of John Dickinson and Company. He was gratified to find that after all the results of the gauges did, according to the author, afford a comparatively trustworthy means of judging as to the amount of water that would find its way into a stream in a district where the rivers flowed upon a pervious soil like chalk. He (Sir John) had never maintained that the Dalton gauges were perfect instruments like barometers or thermometers. It was evident that in filling the gauge with soil the actual condition of the soil in the neighbourhood could not be reproduced, and that there were certain accidental circumstances that would interfere from time to time with the trustworthy character of the results. They talked of gauges 3 feet deep, but the 3 feet had a sub-layer of gravel, so that practically the amount of soil through which the water percolated was not more than 2 feet 6 inches. Where there was vegetation at the top there was a liability of roots extending through the whole depth of the soil, and as those decayed they might interfere with the results. If worms were included in the gauge and increased and multiplied, they would add materially to the permeability of the soil, which would be pretty well riddled with passages. It could only be from such causes as he had indicated that they found a great discrepancy between the results of gauges under precisely similar conditions. That had gone a great way to diminish the confidence that he had in the accuracy of the results of gauging, though he never maintained that they were really accurate.

With regard to the deep gauge with 5 feet of sand, it was very frequently the case that the shallower gauge, with 3 feet only, would show very nearly as much as the deep one, and in some cases an actual excess. The deep and shallow gauges corresponded very fairly together in sand. The water was rapidly conveyed through the sand, and when once it got into the receiver there was an end of it. The difference between the deep chalk and the 3-feet chalk was small in some cases, being about an inch. With regard to earth gauges, a larger amount sometimes went through the deep earth than through the 3 feet, but, generally speaking, it was very much the same. There was another disadvantage in the comparatively shallow gauges, and that was that where in nature there was a great thickness of continuous chalk, it would draw up by capillary attraction from a very considerable depth in excess of either 3 or 5 feet, whereas in the gauges it was not able to do anything of the kind. Directly the water had passed through the gauge, it ceased to be available for the purposes of evaporation or vegetation. For those reasons he was inclined to think that after all, though he did not approve of the Rothamsted gauges at first, they would get more accurate results from the bare soil than from gauges on which there was vegetation, which always differed in different seasons and might differ in different gauges. The Rothamsted gauges, with a certain amount of allowance for evaporation and water consumed by vegetation, would give a more accurate idea of the amount of water passing through a given depth of soil than if an attempt was made to cultivate the surface.

There appeared to him to be a fallacy running through the greater part of the paper, where an attempt was made to compare the total amount of the percolation with the total amount of the rainfall during the year. Sometimes there was a separation made between the winter and the summer, but if they brought in the summer months they at once destroyed all calculations with regard to the amount of the rainfall that went through the gauges or found its way through the soil to serve the streams. He thought they all agreed that the amount of rain that found its way to a depth of 3 feet in the soil during the summer months was comparatively insignificant. It rarely exceeded an inch or two inches at the outside. In the year 1870, with a rainfall of upwards of 16 inches in the summer months, not a single drop found its way through a gauge only 3 feet in depth. Another thing to be taken into account was the manner in which the rain fell. If they had only small showers with brisk east winds intervening between them, they would have hardly any percolation. On the other hand, if they had continuous rain which soaked the soil, when once the water began to pass through the gauge it would pass almost continuously. He thought that in that way the discrepancies between the Old Ford and Dalton gauges and those at Nash Mills might be to some extent accounted for. The position in the one case was considerably lower than in the other, and no doubt there was a difference in the rainfall. In the case of Old Ford and Lea, if they took the whole year, a thunderstorm at one place might destroy the comparison between the gaugings of the two for that year.

Coming to the most valuable part of the paper, the actual gauging of the rivers, it appeared that on the whole the results of percolation gauges indicated that a larger amount found its way into the soil than really did so. Reading between the lines, he was led to infer that one of the objects of the paper was to induce people to believe that in the valley of the Lea and in the valley of the Thames there were hundreds of millions of gallons of water flowing to waste in an uncertain direction which might be tapped and employed for useful purposes. No doubt Mr. Middleton would acknowledge that that possibly influenced him in producing the paper to which they had listened with so much pleasure. He (the speaker) would point out that so far as the river Lea was concerned there was one very important element in the comparison of the rainfall and the flow in the river, and that was the amount of pumping that took place by the New River Company, and also, he believed, by the East London Water Company for their wells. That, of course, abstracted water from the subterranean reservoir in the chalk. By that means the level of that reservoir was lowered, and it took a certain amount of the water that percolated through the earth to fill up the reservoir. He thought that there had been rather an over-estimation of the amount of pervious rocks in the Thames basin. Under any circumstances he could not accept the view that 697 million gallons of water daily found their way out of the Thames valley by some unknown channels. Any one who would study the geology of the country would find that access to the sea, which was the only place to which the water could go, was barred by beds of clay. They could not, therefore, by any possibility suppose that there was this amount of water actually flowing to waste, otherwise it would be seen on the surface, as it would be impossible for it to get away. But assuming that it did get away, pumping from it would not stop that leakage. Assuming that the water was running away in that manner and they were to sink a well in the neighbourhood of a river to intercept the water, the water pumped would be water taken from the river, and it would not stop the flow of water through that large area from which the 697 million gallons were escaping daily. Pumping from a cistern with a leak in it would not stop the leak, though assuming that the water came into the cistern at the same rate only as it leaked away, it would lower the level. If there were a leak, which he doubted, no pumping from the supposed available quantity of water would prevent the escape going on.

The author had bestowed a great amount of trouble upon analysing the results of different gaugings. He (Sir John) wished to express his general concurrence in the view that it was far better to attend to results from an average of gauges kept under slightly differing conditions, at different places, than to rely upon a single gauge. When they reconstructed the gauges at Nash Mills, they put down no fewer than six, namely, one deep sand, one shallow sand, one deep chalk, one shallow chalk, one deep soil, and one shallow soil. The gauges showed that, however perfectly they might attempt to make an instrument of that kind, such as a Dalton gauge, they were still liable to circumstances which might to some extent vitiate the results, though the general results were true and showed that the evaporation which took place from April to September was sufficient to prevent nearly the whole rainfall finding its way to a depth of 3 feet, whereas in the winter months a very large proportion would find its way into the soil. But even during the winter months the different manner in which the rain fell, the varying amount of wind, the frost and other circumstances would affect the results, and affect them differently in different places.

Mr. BALDWIN LATHAM said he thought that the reasons which Sir John Evans had given for the variations from year to year in the percolation gauges must appeal to the sense of every one who understood the question, and they were probably an explanation of many of what appeared to be irregularities in the working of the gauges. One point that he did not touch upon sufficiently, perhaps, was in reference to vegetation. Twenty years ago, in starting the gaugings on the Croydon area he (the speaker) made two percolation gauges which had been working constantly since then. One was a section cut out of one of the Surrey Downs with its natural turf, and the other was a section cut out of the old town of Croydon, practically gravel with herbage upon it. After about sixteen years he found that the vegetation which was natural to the downs had changed its character and was putting on a new garment altogether, and growing at a very different rate to the rate at which herbage on the downs generally grew. Two years ago he obtained permission from the Corporation of London to cut another yard of turf off Riddlesdown. This turf he put on the gauge, removing the old turf, so that that would make some little discrepancy in the working of the gauges, but it was found to be absolutely essential as the gauge was not working up to the conditions which it formerly worked up to. The reason was probably the greater amount of vegetation, the greater amount of evaporation, the greater degree of the drying of the percolation gauge, and the less quantity of water passing.

He had taken the precaution to have the grass cut off his gauges every year and weighed. In the weight of grass grown they had some idea of the amount of evaporation which had taken place from year to year. The weight varied enormously, and that again was one of the questions which affected percolation. His gauges showed very clearly that more water passed through a chalk percolating gauge than actually flowed off a chalk area. In the same period, 1879 to 1894, taking an ordinary year, he found that the average percolation through a chalk gauge was 11·18 inches at Croydon out of a rainfall of 26·08 inches. The rainfall of the Croydon area of the Wandle was 31·13 inches, but the actual flow off was 9·24 inches. As Sir John Evans had said, the reason for that was that with a percolation gauge the water went through and was caught at once, but when rain percolated through the soil and passed to the underground water-level it had to remain there for months. In fact, in a particular year it would be the rain that fell many previous years ago that was flowing away by the springs. The water entering the soil displaced so much water in the chalk which passed down to the water line, and in that process percolation took place. The temperature of deep underground water was always higher than the mean temperature of the air, and the water was always giving off vapour, so that percolation in the shallow gauge must, to be correct, always exceed the quantity shown to be flowing away from the drainage area with a similar kind of soil.

With regard to his gravel gauge, there had not been a single month this year, although a dry one, without percolation. The total amount of water passing through the chalk gauge (up to date) this year was less than 2¼ inches, but through the gravel gauge a smaller quantity had passed. Very small quantities had passed through for the last five months, varying from 1·4 inches in January to ·0006 in August. In the course of his investigations with regard to underground water he had found that at certain periods in the very driest years, when the ground received water by condensation, the degree of condensation was actually measurable in many percolation gauges. He had had an apparatus made consisting of a cylinder of earth working freely in the ground at different depths, by which the amount of water in the earth at different depths was measurable. On a warm day the earth increased in weight, and at night the weight decreased.

He could not reconcile the discrepancies between the actual gaugings of the River Lea and the percolation gauges at Nash Mills. His impression was that soil gauges always gave less percolation if there was vegetation of more than an average character upon them. Nash Mill, on a long average, appeared to give less than the flow off the River Lea. He could not understand how it was possible to show small quantities flowed from the River Lea. From the corrected gaugings of the River Lea, which were given by Mr. Bryan, he found that for the years 1880–91 8·37 inches flowed off. In the same years on the Wandle area 9·05 inches flowed off. The rainfall on the Croydon area was heavier than on the Lea, which accounted for the difference in the figures and tended to prove the correctness of Mr. Bryan's figures. The author gave as the underground flow of the Lea 6700 cubic feet a minute, as distinguished from the flood flow. He had not told them what he meant by flood flow. Did he mean by flood flow the quantity in excess of the mean flow of the river? If so, was it the excess in any one year or any series of years? From the late Mr. Charles Graves's papers he (Mr. Baldwin Latham) found what flood flow in the River Lea meant. It was simply the excess, for the time being, of the ordinary flow, and it could not apply to the whole area of the Lea. There was no such thing as a flood flow off the chalk area, and there were no streams in the chalk area unless they passed over the line of saturation. The whole area of the Lea that would yield floods was about 69 miles. If they took 3·7 inches as the underground water, and 4·58 inches as the flood water, the flood water could not apply to the area which never contributed floods. Therefore there must be a grievous error in the figures. If the actual gauging of the River Lea was 9 inches, and if the 69 miles yielded all the flood, then that area which was of a more or less impermeable, clayey, character, ought to yield four or five times as much water as the chalk area. Did a clay area or a chalk area yield the most water? Waters flowing away in time of flood carried away a very large amount of rain, but when they came to deal with the actual rain falling over an area in a particular year they found that clay absorbed an enormous amount of water, and the evaporation was so great that all the water within the influence of evaporation was absorbed. The loss on a clay area was infinitely greater than it was on a chalk area where the water had sunk beyond the reach of evaporation, except so far as he had already referred to.

He had looked at some of the flood years in the River Lea. One of the largest floods on record was on the 24th October, 1857, when the actual flood water was given at 96,139 cubic feet a minute out of a total flow on that day at Feilde's Weir of 98,186. Divided by 420 square miles it gave 233·77 cubic feet per mile per minute. Dividing the 69 miles by the 96,000 cubic feet they got 1393·3 as the maximum flood water ever recorded in the Lea. The biggest flood in the Graveney, which drains a clay area and which he had gauged every day for seven years, instead of yielding 1393 had yielded 1713 cubic feet a minute. The area was smaller, but it was a long narrow river. That showed that the flood waters were yielded by the 69 square miles, and not by the total area of the river. In the seven years that the Graveney was gauged the actual depth flowing off was 5·08 inches. In the same period 10·40 inches flowed off the chalk area, so that chalk compared with clay actually gave just double the quantity. Whereas it was supposed that only 3·7 inches of underground water had passed away from the chalk area, probably 9 or 10 inches had done so. The large quantity of water which the author imagined, was certainly non-existent when they came to deal with the actual facts. He (Mr. Latham) had surveyed the River Lea and its neighbourhood many times, and a mere dribble of water got into the great underground depression under London. How it was possible for any of the waters, which they knew were many feet below the level of the sea, to come down the Thames in one direction, and down the Lea and jump over the great gulf which had been caused by pumping in and around London, and then to pass out again on the opposite side of that gulf, was a perfect mystery to him. The explanation was that the amount of water lost upon the impermeable strata was much greater than anticipated by the author, while the amount of water yielded by the chalk was double that stated by the author. He was very much indebted to the author for the figures which he had given. They would be extremely useful.

With reference to the calculation of gradients of underground waters, he (the speaker) was once of opinion, until he found out the contrary by actual surveys, that it did not always follow that the steepest gradients occurred at the highest water periods. He found that under the very highest ground there were, as a rule, very often formed great knolls of water. The fluctuation in the wells in some of these high grounds was very striking, and was often much less than that in wells nearer the point of the escape of the underground water. As a general rule, when underground water was following down a valley line as you left the point from which the stream escaped, as you passsed upwards the rate of fluctuation in the wells rose, but there were most marked exceptions to that rule.

With reference to the well of Barley, when the records came into his hands he re-measured it and a good many other wells in the country. Barley well was now measured twice a week at his expense, and the records could be supplied up to date if any one wanted them. But Barley well was not within the River Lea watershed, therefore it could not be used for the purposes of making any calculation with regard to the River Lea. He had been most fortunate in getting records with respect to wells. One of the most extraordinary was a record of some thirty or forty wells in the valley along the Kennet and Avon Canal, originally begun in 1835 by Mr. Blackwell, a very celebrated man in connection with water questions, and was continued until 1863. There was also a record at Long Wittenham by Mr. Clutterbuck, and continued by his son. All the records were of infinite value because they all tended to confirm the state of the rivers. A properly authenticated well record within the area of a district to be gauged would give knowledge with regard to the springs which could only be acquired by a tedious and expensive process of gauging over a long period, the result of which might be somewhat vitiated by questions of surface water.

Professor Henry Robinson said that, with regard to percolation gauges and the accuracy which was claimed for them, one matter of common knowledge might be mentioned to show that all water that was gauged did not go into the subsoil. He referred to the chalk areas round Salisbury, where, if it was not for the amount of water deposited in the dew ponds by evaporation and condensation, in times of drought the cattle would have no water. All that water was drawn up from the substrata. He knew of a case within the last year or two where the discrepancy between the calculated amount of water expected to run into a reservoir off a gathering ground and that which actually ran into it, was ascertained by him (Professor Robinson) to be due to a large part of the drainage area being fissured in places which would not have been indicated by a gauge, and the bulk of the showers and rainfall during times of drought disappeared into the subsoil. He felt that even those who differed from Mr. Middleton in his broad conclusions were agreed that one who would take the trouble to produce such a mass of information with the care and accuracy which he had manifested, deserved the thanks of all. He (Professor Robinson) was not prepared for the suggestion that had been thrown out, of the paper having been written for the purpose of dealing with the large question of London water, and he had not come prepared to take part in the discussion beyond the scope of the paper itself. He thought that if they imported into the discussion the great question of the metropolitan water supply, they would get upon very ticklish ground.

Mr. J. Francis said that he could not corroborate the figures given by Mr. Middleton as to the quantities of water passing away from the Lea basin and the Thames basin without flowing down the channels of the rivers, nor could he go into the figures that Mr. Baldwin Latham had given to show that those quantities of water did not exist; but it seemed to him to be a perfectly reasonable belief that they should exist. The difference of opinion seemed to arise entirely from the holding of two different theories, which had been discussed before the recent Royal Commission on Water Supply, and had been described as the "cistern" theory and the "underground river" theory. Sir John Evans had spoken of the chalk basin as being a cistern. If there was one distinctive characteristic of a cistern, it was that the water surface was at the same level throughout. That did not occur either in the Lea basin or the Thames basin. Everywhere there was a fall from one point to another. In the Lea the general direction was towards the south-east, and to the east of London there were large quantities of water passing into the Thames. Only a small part of that chalk water passed under London. There the chalk seemed to be compressed, and the fissures were small in sectional area, and very deep pumping was necessary to get at the water. The water from the chalk districts to the north of London undoubtedly passed off in a south-easterly direction, and lost itself where the chalk outcropped into the Thames. That there was a large quantity of water going off in that way was, he thought, proved by the fact that, in spite of the increase of pumping that had gone on in the Lea valley for the last twenty years, there had been no diminution in the flow of the Lea itself, as proved by the gaugings. The flow, of course, varied with the seasons. Moreover, there had been no lowering whatever of the levels of the underground water throughout Hertfordshire. On looking at geological maps of the Thames basin, he did not see any difficulty whatever in supposing that a large quantity of water went from the middle or chalk portion of the Thames watershed, passing southward through the chalk towards Hampshire and finding its way into the sea. He thought there was nothing incomprehensible in the suggestions that Mr. Middleton had made.

Sir JOHN EVANS said he did not call the chalk basin a cistern. He merely used a cistern as a simile to show that if such a receptacle were kept full from a tap which just made up for the waste, pumping from the cistern would not stop any leakage, but would merely lower the water. Everybody knew that the surface of the water in the underground reservoir of the chalk was very variable, and that at no two periods of the year was it in exactly the same position or at the same slope.

Professor LOBLEY said he did not consider the cistern was a happy illustration. If they had a cistern with a stream of water running into it, and a leakage at its bottom, the flow of water from the top to the bottom of the cistern was continuous and unimpeded; but the flow of water from the uppermost beds of the chalk to the lowermost beds was very much impeded. In fact, it took a long time for the water to get through, and so drawing upon the lower waters might save that now wasted by leakage. Moreover, if there was a reservoir of water at a considerable depth in the chalk with rivers on the surface, wells sunk to the bottom of the reservoir might take out a considerable quantity of water without affecting that in the rivers, since it would be water that could not enter those rivers. On the face of it, he thought they must consider that there was a very large quantity of water flowing away to waste from the basins of the Thames and Lea. Every one knew that a chalk area was practically a streamless district, with the exception of its rivers, as there were no streams intersecting the land as in a clay area. There were, therefore, very large areas of land on which the rainfall did not feed the rivers, but, by percolation, fed the reservoir in the lower portions of the chalk. The chalk area to the north of London gradually sloped down from north to south, and the upper beds of the chalk were at the southern boundary of the area, just at the edge of the London clay of the Thames Basin. There was thus a large area of chalk that received a rainfall which could not get into the rivers, because it sank lower than the level of the bottom of the rivers at their lowest levels in the chalk area. Presumably it escaped at the still lower levels, where the chalk cropped out at about the mouth of the River Thames. He saw no geological difficulty whatever in allowing for such an issue of the lower water of the chalk of the Lea and Lower Thames Basins.

Mr. R. H. TWIGG said he had been interested in the question of percolation for over thirty-five years, and had watched the different results obtained during that period. He first attacked the question practically in consequence of what had gone on at Nash Mills. The gauge there was originally of wood, and was found to be rotten; iron was then substituted. He put down at Bulbourne, 400 feet above sea level, a cast-iron gauge three feet diameter and four feet deep, filled to correspond with the adjacent soil and subsoil, which was chalk. From October 1862 to May 1863 inclusive, it gave 7·07 inches percolation; from June to October 1863, inclusive, no water passed. Then, from November 1863 to April 1864, 3·6 inches passed, the total percolation during the period being 10·677 inches. Practically there were two seasons' percolation. That gave only 5 inches per annum. The rainfall from October 1862 to April 1864 was 32·96 inches. During 1883 he gauged the river Bulbourne at several places. At Box Moor it gave a depth of 5·8 inches running off, and at Hunton Bridge 7·2 inches. The Colne at Denham gave 5·8 inches. Those figures corresponded very closely with his gauge, which was fixed in a grass plot, and was approached by a well with steps. A vent at the bottom passed the percolated water into a bottle. He did not think greater precaution could have been taken to obtain correct results.

He thought Mr. Middleton might have given in his paper drawings and descriptions of the gauges referred to. What was the good of arguing upon doubtful premises? For instance, until the question of the form of rain gauges and their position was carefully studied, the results could not be relied upon. He remembered two gauges at Liverpool. One gave 50 per cent. more than the other. But one was on the roof of a house and the other on the ground. There was a well at Nash Mills, and the gauge was three feet from it. Too much reliance should not be placed upon the old records of percolation gauges.

With regard to the River Lea, he had worked out the forms recording the gaugings. The floods were recorded when certain boards were taken off the weir. It was a mistake to assume that the floods so recorded showed all that came from the sixty odd square miles of clay ground, for while the chalk was draining there was something coming from the clay ground while the boards were on. He knew a clay field of about 20 acres where, when a downpour of rain came, the water ran off immediately, and then the flow stopped. That field was deep drained, and, if he remembered rightly, the water then ran from it continuously for nine months out of the twelve. If the chalk was credited with all except floods passing when the boards were off, it was credited with too much, and the clay was not credited with enough. He could not conceive that clay should be deemed such an inferior surface for yielding water when the Kingsbury reservoir area yielded 13 inches per annum on an average, and the chalk, if his percolation gauge was right, yielded probably 6 inches. The Kingsbury reservoir area was a valuable one to study, because it was almost all clay. They got 13 inches from that, but what became of the remaining 12 inches? It had to go away either by direct evaporation from the surface or from the leaves of plants. The district was practically entirely grass land. People should remember when calculating the areas with regard to percolation that in timbered country there was hardly any percolation at all, probably less than two inches in the course of the year. Hedges would have a very great effect, because rainfall would evaporate from the branches and leaves, and hardly a drop would come to the ground. He believed the only proper way to construct a thoroughly reliable percolation gauge would be to take a piece of the natural ground, say 50 feet square, and put round it a concrete wall, and then, by undercutting, put a watertight bottom to it. It would be costly, but worth the money, because it would set the whole question at rest. Existing percolation gauges were leading people into the error of supposing that a greater quantity of water percolated in chalk areas to feed the springs than really did so.

There was a great want of care in speaking of percolation. The only water that ought to be caught in a percolation gauge was water that would never return to the surface of the earth again, except in the form of springs.

Mr. Baldwin Latham said, with reference to the remarks of Mr. Twigg, that a great number of experiments had been made upon the question of porous soils and impervious soils.

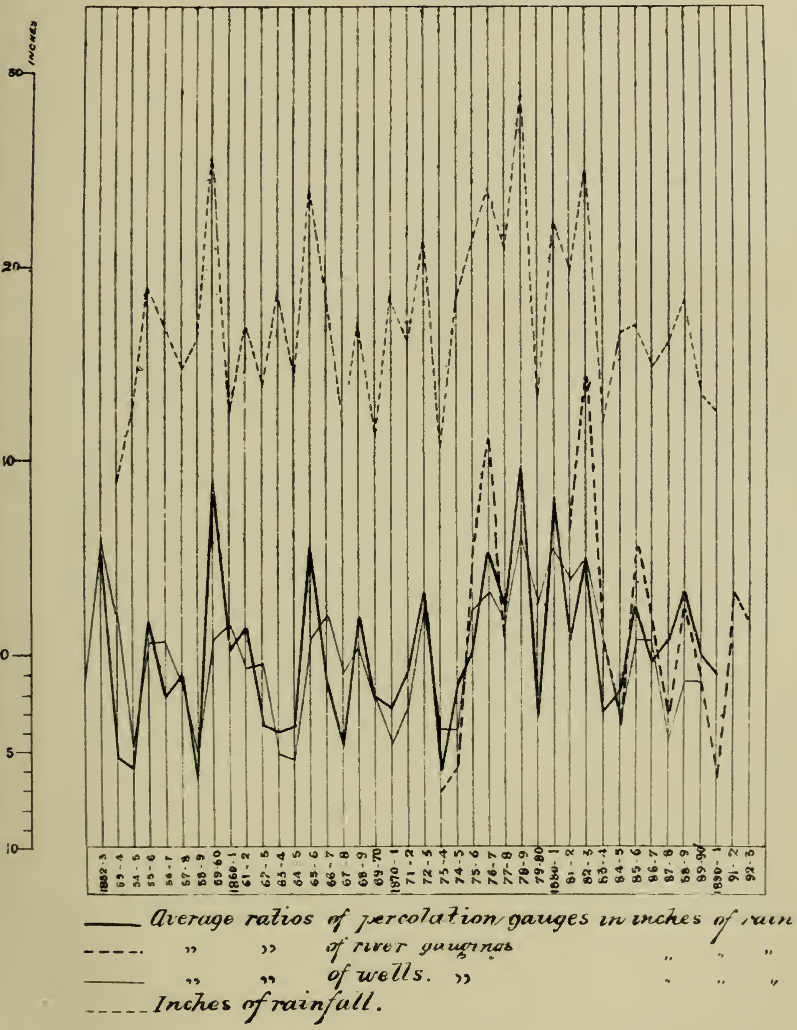
The Hinxworth experiments of Mr. Bailey Denton and others all showed that an impermeable soil passed off very much less water in the course of a year than a porous soil. In the figures that he had given in regard to the River Graveney, of course he had taken a whole year. He had not dealt with flood water. The 5 inches in the one case, and the 10 inches in the other, in the same seven years, were the figures dealing with all the water flowing away. He was quite aware that for some days in a dry year no water flowed off from areas of an impermeable character, but the great quantity flowing off such area went away in floods. If they took all over the average each year as flood water, then the seven years gaugings of the River Graveney showed that 62·5 per cent. of all the water flowed away as flood water in less than 73 days. It was not clear whether flood water ought to be estimated in that way, or whether it ought not to be estimated as the excess of the mean quantity spread over the whole period of gauging. At present he had dealt with it over one particular year, and consequently, as the volumes in different years varied enormously, there was a great disproportion in what was flood water. In dry years floods were recorded which, occurring in the same volume in a year of considerable flow, would not be counted as floods.

Mr. MIDDLETON, in reply, said that Sir John Evans began by saying that gauges were not perfect. He (the author) had not the slightest intention of attacking gauges in his paper. He simply wished to show that there was a means of corroborating them. He did not wish to emphasize the enormous differences between gauges, and to say that therefore they were imperfect. That fact was, he was sure, plain to all users of them. The object of his paper when he began to write it, was not, as Sir John Evans had been kind enough to suggest, directed to the question of the enormous quantity of underground water which might be obtained by pumping, but it was written simply with the intention of ascertaining a means of corroborating the records of percolation gauges, and showing whether they were in agreement with other sources of information. He believed that he had been able to show that, taken on the average, they were in agreement with something that he had been able to define. He trusted that that something might be useful in the future. With regard to the necessity for separating summer and winter gaugings, he thoroughly agreed with Sir John Evans. He would not only separate the summer and winter gaugings, but he would separate every month, or even every day. Unfortunately, when he wrote the paper he had nothing (with the exception of a few of the gaugings of the Thames and Lea) but the records supplied by Dr. Hopkinson. Those records were made up in winter and summer periods, and he had not been able to go into a greater subdivision than he had done. He wished he had been able to get further information, but he had not had the advantage which Sir John Evans and Mr. Baldwin Latham had in having gauges of his own or access to the gauges of others. Therefore he had been obliged to lay before the Society a paper which was, in that respect, defective, and which he should have been very glad to make more perfect.

Sir John Evans had spoken of the question of reservoirs, and he said that if they poured water into the top of a reservoir and it leaked out at the bottom, and if they pumped at the same time, they reduced the level of the water in the reservoir, but did not stop the leak. He quite agreed, but that was not the position of the reservoir in the chalk. There they were pouring water down a slope and letting it run off at the top, or lip, not at the bottom. Therefore if they began to pump near the edge they stopped the water from running over the lip and no more. They did not stop any leak at the bottom, because there was none. The leak could only take place at the level of the sea. The bottom of the reservoir was many hundred feet below sea level. It had been said that water pumped from a well must necessarily lower the river. He had had several opportunities of showing that that was incorrect. Going alongside the River Lea he had examined a large number of wells. In many cases he had found that the level of the water, no matter what time of the year it was, was below the level of the river, though the wells were working in sympathy with the river. The reason for that was that the river had been canalised. The water had been unable to leak out of the well, and, being at a lower level than the river, it was pretty clear that it could not get into the river.

Mr. Baldwin Latham's array of figures was so great that he (the speaker) could not possibly attempt to deal with it fully, but he would ask him whether or not it was true that the amount of water finding its way into the river from spring sources was greatest about March, and least about November; and was that not proved from the gaugings of the year 1874, during which there was practically no flood water in the river at all? The quantity of water, which was always spring water, going into the river in that year was about the amount that he had given, namely, about 60 millions. There were other years in which practically nothing but spring water went into the river. In 1864 there were, he thought, 62 million gallons. If the figures that he had given were multiplied in some way into the rainfall of the particular year, the probabilities were that the amount of spring water running into the river for, say three months after, and for the year following, would more closely correspond than the average figure which he had given. He thought that the fact that in 1864 and 1874 there was practically nothing but spring water going into the river, and that that water measured the quantity that he had stated, was a proof that wells did not discharge a deal more in the winter than in the summer. When the level of the water was at its lowest, the spring water in the river would also be at its lowest; when at its highest, the level of the spring water flowing into the river would also be at its highest. If that were true they found that a measurement of the storm water—meaning by storm water, everything in excess of the water coming from the underground sources—represented a figure which closely corresponded with the ratio of the gaugings. From that figure, representing the rainfall over the whole area, a fair estimate could be made of the amount of percolation over the whole area, the only thing being that they would have to assume a figure of percolation. That figure he had taken at 10 inches, because Mr. Latham and many other eminent engineers had said that it was 10 inches. In his own figures he had assumed that it was 9·10 inches, but he had always said that it probably exceeded that, not because he had means of being certain, but because eminent engineers and geologists had said that it did. Mr. Latham had said that all the storm water came off the clay. If that was so, it was very curious. He had examined the rivers in the summer, and in the winter, indeed all through the year, and certainly there was very much more water passing from them in the winter, during parts of the season, than in the summer, and it could not be accounted for entirely by water flowing off the clay level. Then, on the other hand, a great deal of the water passed into the chalk, and when there was a particularly big rush, it passed over the chalk into the river, and though it really belonged to the chalk basin, for the moment it became flood water. With all due deference to Mr. Latham, he must stick to his opinion that there was a discrepancy between the figures of percolation and between the gauging of the rivers, and that there was a quantity of water in the underground reservoir which could be pumped from and used for the purposes of supply, without interfering with the river itself. He was perfectly aware that Barley Well was outside the watershed of the Lea, but the rainfall of that part was well known, and although the water from the Barley Well flowed in a contrary direction, he did not see that that at all interfered with its being used as a comparison with the flow of the Lea. It was all within the same district, and it was only on the other side of the gradient line of the Lea valley by about a mile and three-quarters or two miles. There was nothing to prevent that well being used for the purpose of gauging, though of course if he had had the records of other wells to refer to he would have used them.

DIAGRAM.



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WILLIAM G. PEIRCE, President, in the Chair.

THE EFFECT OF STRAIN ON RAILWAY AXLES, AND THE MINIMUM FLEXION RESISTANCE-POINT IN AXLES.*

By Thomas Andrews.

Our knowledge of the influence of stress and strain on the physical properties of metals is comparatively limited, and the author undertook this investigation to obtain, by large scale experiments, additional information on this important subject. Mr. James E. Howard, C.E., Engineer of Tests, U.S. Arsenal, Watertown, Mass., has recently remarked: "The relations which exist among the several properties, and the influences which promote durability in metals, we must admit, are in a state of deep obscurity." The elaborate and valuable researches of Wohler, and those of Bauschinger, have, however, increased our knowledge as to the influence of prolonged stress and strains on metals. Other equally interesting researches have also been made by Styffe, Kirkaldy, Rodman, Thurston, Beardslee, Vicat, Spangenberg, Barus and Strauhal, Baker, Kennedy, Martens, W. P. Hunt, E. C. Felton, and others.

Egglestone, in his researches on the behaviour of metals under long-continued stresses, accumulated information indicating "a law of fatigue and refreshment of metals," identical with that observed by Prof. Thurston. He also produced evidence indicating the tendency to crystallisation in metal whilst undergoing the fatigue of strain, and has further stated that "the change produced is a chemical one" (Trans. Inst. Mining Engineers, 1880).

In the experiments of the present paper, the author has endeavoured to examine other aspects of the influence of stress and strain on metals, and the conclusions he has arrived at, as the result of a different and independent series of experiments, are generally somewhat coincident with those of Egglestone and others, to which reference has just been made.

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* The Bessemer Premium was awarded to the author for this paper.

The author thought it might be of interest and utility to endeavour to obtain an accurate approximate estimate of the total number of railway axles running on all the known railways throughout the world, and at the same time to make, in cases where possible, an estimate of the actual carrying work performed by each axle per annum. This task was found to be no easy one, and the author is not aware that it has been previously attempted, but he has endeavoured to embody, on Table I., as accurate information as it is possible to obtain on such a cosmopolitan subject. Apart from the enhanced interest these results afford to the present paper, the information may possibly also prove of assistance in the endeavour to determine approximately the period which should be fixed as the limit for the safe working-life of railway axles.

From the results in the above table, it will be seen that up to the end of 1891 there was a grand cosmopolitan total of more than 5,773,837 railway axles running in the world. When it is remembered that this great number of axles are daily subjected to the varying destructive stress and strain of actual wear, a study of some of the probable causes leading to their deterioration cannot fail to be of interest to railway engineers.

In order that a nearer approximation might be obtained to what occurs in actual practice, the author decided to experiment upon railway axles to the specifications and dimensions of those actually running at the present time. The experiments of Sets I. to XII. inclusive, on wrought-iron railway axles, were made on best fagotted railway axles, manufactured at the Wortley Iron Works, near Sheffield, and they were all manipulated in the same manner by the methods uniformly in use at these iron works. They were selected variously from orders on hand for England and abroad. The brand of the axles was that generally known as "Wortley." The dimensions of the axles were as follows:—

	ft.	in.
Total length of axle	6	11¾
Length from centre to centre of journals ..	6	3
„ of wheel seats	0	11½
„ of journals	0	6½
„ of end collars	0	1⅛
Diameter of middles	0	4⅜
„ of wheel seats	0	5½
„ of journals	0	4
„ of end collars	0	5

An indication of the normal physical properties of the wrought-iron axles is given in Set XI., Table XII. The wrought-iron axles used in the experiments of Set XII. were 4½ inches diameter in the middle.

The tests of the steel railway axles of Sets VIII., IX. and XII. were made on steel axles manufactured variously in the Sheffield district, the steel-making districts of Lancashire and Scotland, and some were of Belgian manufacture.

The axles were variously made by the well-known processes of Bessemer and Siemens, and were selected from orders on hand for England and abroad. The dimensions are given in the respective tables of each set of experiments. The physical properties of the steel axles are shown by the tensile tests which are given on Set XI., Tables XIII. and XIV.

METHOD OF EXPERIMENTATION.

The experiments were arranged in the following sets, and some of them were designed to show the influence of temperature, in combination with pressure, on the rigidity and physical properties of railway axles.

Set I.—A series of experiments on the increase of rigidity of railway axles under the influence of an increasing series of slow flexion strains produced by hydraulic pressure, the time duration of pressure producing each flexion being 30 seconds in each case, and five minutes elapsed between each flexion. The axles were at the temperature of 50° F., or 10° C.

Set II.—Experiments on the increase of rigidity of railway axles under the influence of flexion strain at the temperature of zero (0°) F., or – 18° C., under the conditions given on Table III.

Set III.—Observations on the increased rigidity of railway axles under flexion strain, as stated on Table IV., at the temperature of 100° F., or 38° C.

Set IV.—Experiments similar to those of Set III., but with the axles at the temperature of 212° F., or 100° C.

Set V.—Experiments analogous to those of Set IV., the axles being at the temperature of 572° F., or 300° C.

Set VI.—Experiments similar to the above, but with the axles at a temperature of 842° F., or 450° C. These experiments indicated an increase of about 72 per cent. in the total resistance of railway axles at this temperature to the influence of slow flexion strains when compared with the results of Set V.

Set VII.—Observations of a similar kind, the axles, however, being at the temperature of 1112° F., or 600° C. In connection with this set, observations were also made on the effect of slow flexion strain on railway axles at the temperature of 1472° F., or 800° C.

Set VIII.—Tensile tests showing the extent to which the slow and repeated flexion strains, given in Set I., Table II., had affected the physical properties of the axles experimented upon.

Set IX.—Observations on the influence of torsional strain on the rigidity and physical properties of railway axles at ordinary normal temperature.

Set X.—Experiments on the effect of tensile strain on the rigidity and physical properties of railway axles at normal temperature.

Set XI.—Tensile tests of the wrought-iron, Siemens-steel, and Bessemer-steel axles employed in the experiments of Set XII.

Set XII.—Experiments on the effect of repeated heavy impact strain relatively on the rigidity of wrought-iron railway axles, Siemens-steel railway axles, and Bessemer-steel railway axles, at normal temperature. This set also contains some experiments on the effect of impact strain on the rigidity of wrought-iron railway axles at higher temperatures.

The experiments of Sets I., II., III., IV., V., VI. and VII., on the influence of flexion stress on the rigidity of railway axles were conducted as follows. A suitable powerful hydraulic apparatus was contrived to give the bending pressure required: the apparatus as used in making the flexion tests is shown in part in Fig. 1.

It may be mentioned that the pumps connected with the hydraulic testing apparatus consisted of a set of six-throw machine-driven pressure pumps, with plungers 1⅝ inch diameter. This was arranged so that the pressure might be of a steady uniform character, and devoid of the fluctuations which a two-throw or even a three-throw set of pumps might have caused.

In conducting the experiments an axle was placed on the supports, which were 3 feet 6 inches apart at the datum points, and slowly bent by the hydraulic pressure until a deflection of 2 inches was obtained between the bearings; the force was then taken off the axle. After the first deflection the axle was half turned over to an angle of 180°, and the bending pressure reapplied and continued until the axle was straightened and the record of pressures and other observations recorded. Pressure was then further applied, sufficient to bend the axle in the same direction, until a deflection of 2 inches was reached, and observations were again taken at this point. The axle was afterwards turned half over, to an angle of 180°, and the operations were repeated, according to the number of flexions required, with the detailed results recorded in Sets I., II., III., IV., V., VI. and VII.

An arrangement was made so that each end of the axle undergoing test was free to roll endways along the bearings during the process of flexion. This was a matter of importance, and was designed to prevent any frictional binding of the axle in the bearings arising from the great pressure required to bend such large forgings. If the axle during testing had become fast bound by the hydraulic pressure, so as to prevent the lateral motion at each end, consequent on bending, a considerable amount of tensile strain would have been set up, which would have interfered with the accuracy of the flexion results. This liability to error was obviated by introducing a turned steel bar or roller into each bearing, which allowed the axle placed thereon to have free lateral motion, although at the same time it was enduring the heavy pressure, often approaching 60 tons, required to bend it. The force required to produce flexion was ascertained by calculation from the readings of the hydraulic pressure-gauge attached to the testing apparatus.

The axles used in the experiments of Set II. were reduced to, and maintained at the required temperature of zero (0°) F. by prolonged immersion in a freezing mixture, of two parts by weight of snow and one part salt, contained in a large freezing tank conveniently adjacent to the testing apparatus. Thermometer observations were frequently taken, and the freezing mixture was constantly renewed, to ensure accuracy of temperature. Previous to placing on the testing apparatus, each axle remained for about four hours immersed in the freezing mixture, until the forging was at a uniform temperature of zero (0°) F. The axle was then removed to the testing apparatus, and received one flexion; it was then re-immersed for a quarter of an hour in the freezing tank, and again replaced on the testing machine, and this was continued to the termination of each experiment.

The axles employed in the experiments of Sets I., III. and IV. were kept at the respective temperatures of 50° F., or 10° C., 100° F., or 38° C., and 212° F., or 100° C., by immersion in large water baths of the required temperature, in which thermometers were placed for regular observation. Previous to commencing the tests each axle was gradually raised to the required temperature in the water bath, and was replaced therein after each flexion for a quarter of an hour. It will be thus seen that observations on the increased rigidity of railway axles were obtained within a wide range of temperature, and some interesting results were noticed, which are described later on.

The experiments of Set I., Table II., conducted at a temperature of 50° F., or 10° C., were arranged into—Series A, axles which received only one flexion; Series B, axles receiving two flexions; Series C, axles submitted to four bendings; Series D, axles bent eight times; Series E, axles receiving twelve flexions. The number of test flexions was thus varied in this set of observations so as to ascertain the extent, if any, to which bending, after the first flexion, might subsequently affect the physical properties of the metal; and the results are given on Set VIII., Table IX.

The axles used in the experiments of Set V. were raised to and kept at the required temperature of 572° F., or 300° C., by immersion in a large oil bath, each axle being replaced in the bath after each separate flexion for a quarter of an hour.

The axles experimented on in Set VI. were heated to and maintained at the temperature of 842° F., or 450° C., by immersion in a large sand bath, placed inside a furnace, in which a uniform temperature was carefully maintained, as ascertained by frequent observations with a Siemens pyrometer. Each axle was replaced for a quarter of an hour in the sand-bath furnace after every four flexions in the testing apparatus.

The axles under observation in Set VII. were slowly raised to the required heat of 1112° F., or 600° C., in a muffled furnace, which was kept at an even temperature. Frequent tests of this were made with a Siemens pyrometer. Each axle, after every four flexions, was replaced in the furnace for a quarter of an hour previous to resuming the experiments.

The axles tested in this set at the temperature of 1472° F., or 800° C., were gradually heated to this temperature in the muffled furnace, and steadily maintained at the above heat during the experiment, each axle being returned to the furnace at short intervals in course of each set of experiments. A Siemens' pyrometer was regularly used to ascertain the uniformity of temperature.

The varying rigidity of the axles resulting from the varied number of flexions, and within the wide range of temperature stated on Sets I. to VII., is shown by the actual force in tons which was required to bend the axles. In the experiments of Set I. none of the axles were tested to destruction, but in the subsequent experiments of Sets II., III., IV., V., VI. and VII., the bending was continued until the forgings were broken, which afforded an indication of their relative endurance of repeated flexion at the varied temperatures, and under the conditions stated on each table.

GENERAL RESULTS OF SLOW FLEXION EXPERIMENTS.

Set I.—In these experiments, at the temperature of 50° F., or 10° C., the axles manifested, comparatively with experiments at other temperatures, the greatest rigidity. An average force of 45·24 tons was required to produce the first flexion, which for subsequent flexions had to be increased in some instances to as high as 53·72 tons; the average pressure required to bend the forgings being 50·71 tons. The rigidity of the axles was, on the average, increased by the first flexion 10·94 per cent.; and during subsequent flexions it continued to increase, the maximum being 18·74 per cent., and the average total increase of rigidity from the first to the twelfth flexion was found to be 13·20 per cent. Under the same conditions Bessemer-steel axles increased in rigidity during eight flexions, on the average, 17·86 per cent., and Siemens-steel axles 16·67 per cent. The reduction of resistance to impact stress,* with the decrease of temperature, indicates the increased liability there is of axles fracturing under concussional strain during the prevalence of low temperature.

Set II.—In these observations, at the temperature of zero (0°) F., or − 18° C., an average force not exceeding 50·89 tons was required to make the first flexion; this pressure, however, had gradually to be increased to produce the subsequent bendings, in many instances to as high as 59·38 tons. The total average pressure required to produce fracture of the axles was 1008·47 tons, distributed over eighteen flexions. A maximum increase of rigidity of 16·68 per cent. was noticed; the average total increase of rigidity up to the twelfth blow inclusive being 10·34 per cent.

Set III.—At the temperature of 100° F., or 38° C., at which these experiments were made, an increase in the rigidity was observable. An average force of 46·18 tons was needed to cause the first flexion, but an increase of pressure was required for the after deflections, culminating in a maximum of 57·49 tons. The total average pressure of 971·92 tons was needed to break an axle; the average number of bendings previous to fracture being eighteen. The total average increase of rigidity from the first to the twelfth flexion was 15·73 per cent. A maximum increase of rigidity of 24·49 per cent. was, however, observed in course of the experiments of this set.

Set IV.—The rigidity of the axles in these experiments, made at a temperature of 212° F., or 100° C., was somewhat similar to that of the axles tested at 100° F., or 38° C., though there was a marked decrease in the total endurance of slow flexion at the temperature of 212° F., amounting to 44·44 per cent. compared with axles at the temperature of zero (0°) F., or – 18° C. An average force of 46·18 tons produced the first flexion, the highest pressure noticed in course of the various subsequent bendings being 57·61 tons. It was noticed that the total average pressure required to produce the fracture of an axle in this set of observations was 524·25 tons, and the average number of flexions before fracture occurred was ten. These results indicate a very large decrease in the endurance of slow flexion in the axles at the temperature of 212° F. The total increase of rigidity gradually accumulating from the first to the twelfth bending was 16·14 per cent., though a maximum of 24·75 per cent. was noticed.

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* See the author's research on 'The Effect of Temperature on the Strength of Railway Axles,' Parts i., ii., and iii., Min. Proc. Inst. C.E., vols. lxxxvii., xciv., cv.

Set V.—In this set of observations, at the temperature of 572° F., or 300° C., there was a further very marked decrease of the total resisting power of the axles to slow flexion, amounting roughly to 69 per cent., when contrasted with the total resistance of axles to slow flexion at the temperature of zero (0°) F., or – 18° C. The average force, however, requisite to bend the axles at each flexion was less than those tested under similar conditions at the temperature of 212° F., or 100° C. The actual average force needed to give the first flexion was 45·48 tons, the highest force during the twelve bendings being 57·49 tons. The total average pressure requisite to break the axles was 312·66 tons, the average number of bendings previous to destruction of the axles was six; the increase of rigidity noticed between the first flexion and the twelfth being on the average 18·76 per cent., with a maximum of 26·41 per cent. The behaviour of axles under flexion pressure at the temperature employed in this set of observations is shown to be quite abnormal, and these results confirm the circumstance of iron and steel manifesting brittle properties at temperatures approaching that employed by the author.

Set VI.—The average force needed to make the first flexion in this set of experiments, made at the temperature of 842° F., or 450° C., was 45·24 tons, or about 11·10 per cent. less than when the axles were at the temperature of zero (0°) F., or – 18° C.; the highest pressure recorded in course of the subsequent bendings was 58·25 tons at the eleventh flexion. There was also a very considerable increase of the total endurance of slow flexion previous to final fracture, when compared with similar experiments at the temperature of 572° F., or 300° C., the average total bendings being ten. The total average force essential to produce rupture was 538·63 tons. A maximum increase of rigidity of 28·76 per cent. occurred in course of the experiments, but the average total increase of rigidity accumulating between the first and the twelfth flexion, was 18·06 per cent.

Set VII.—As might be expected at the high temperature of 1112° F., or 600° C., the resistance to flexion was reduced almost to nil. The force essential to produce the first flexion was, however, easily measurable, being 2·83 tons; and a remarkable and extraordinary cumulative increase of rigidity as between the first deflection and subsequent bendings was noticed in this set of experiments, force as high as 8·48 tons being needed to produce the eleventh flexion. This average total cumulative increase of rigidity, from the first to the twelfth flexion, was found to be 123·16 per cent., with a temporary maximum of 199·65 per cent., which is a further most interesting metallurgical result.

The axles endured a comparatively greater number of flexions at this high temperature, but, owing to the comparatively small force requisite to produce each bend, the average number of bends was 23·5, and the total average force producing fracture was only 143·96 tons.

The experiment at the high temperature of 1472° F., or 800° C. (bright red heat) of course showed an almost complete absence of rigidity in the axles under examination. Six axles were examined, and were found to endure on the average 63·5 flexions previous to fracture. The greatest number of bendings being 71, and the lowest 58.

Appearances of Fractures at the various Temperatures.

Another feature of very considerable metallurgical interest in connection with this research, was the varied appearance of the fractures of those axles tested at the different temperatures. The chief characteristic was as follows. The fractures of those axles broken in Set II., at the low temperature of zero (0°) F., presented a generally crystalline aspect; but as the temperature was gradually increased in the subsequent series of tests, as recorded in detail in Sets III., IV., V., VI. and VII., the appearance of the fractures at the higher temperatures gradually assumed a more fibrous character. This was noticeable at the temperatures of 212° F., or 100° C., but very markedly so in the fractures of the axles in Set V., tested at the temperature of 572° F., or 300° C., and also in the subsequent experiments at higher temperatures. In the latter case the fractures presented an unusually fibrous structure. This was a matter of such interest and importance that the author had a series of 17 photographs taken, contrasting the appearance of the fractures of the axles broken at zero (0°) F. with the appearance of those broken at 572° F., or 300° C. Moreover, an examination of the photographs of the fractures shows that in each case the fibrous character of the metal at this temperature had been modified into a crystalline aspect on the alternate side of the axle, at the two places where the force was alternately applied in course of bending the axle, thus indicating that the stress had an influence in producing a crystalline appearance of fracture. This result is visible to the eye, and affords a strong testimony to the view that continued strain induces a crystalline fracture of axles under certain conditions. Moreover, the appearance of the fractures of the test pieces cut from the axles examined by flexion strain, as given in Set II., Table III., further appear to indicate that slow flexion strains at the temperature of zero (0°) F. tended to induce a more crystalline appearance of fracture.

Effect of Flexion Strain on the Physical Properties of Railway Axles.

It seemed desirable to the author to undertake a further series of experiments on the axles examined in Set I., so as to ascertain. by accurate tensile tests, the actual extent to which the physical properties of the metal had become affected by the slow flexion strain which had been applied thereto. A reference to Set I., Table II., will show that the ten axles tested in that set were not tested to destruction, but that the tests were purposely arranged, so that in Series A the axles received only one flexion, in Series B they were submitted to two flexions, in Series C to four bendings, in Series D to eight, and in Series E to twelve bendings.

Portions 1½ inch square and 6 inches long were machined respectively from the side of each axle, at the centre A (see Fig. 2), close to the point where the pressure had been applied to produce flexion; and from the end of the axle at the boss at a point B (see Fig. 2) removed from the flexion strain. These portions, referred to in Set VIII., Table IX., as "strained portion" and "unstrained portion," were turned to suitable dimensions, and their tensile properties examined in the usual manner in a tensile testing apparatus.

Observations were taken in this manner on axles P 3 and P 4, P 7 and P 8, P 9 and P 10 (and on Bessemer-steel and Siemens-steel axles, C, B and W), which had respectively previously received one, eight and twelve flexions under the pressure and other conditions given in detail on Set I., Table II. The results obtained were of a highly interesting character, and are given in detail on Set VIII., Table IX., and afford independent and conclusive testimony to the extent to which the rigidity and other physical properties of railway axles are influenced by flexion strain. In the axles examined by this method the breaking strain was found to have largely increased, and the elongation to have become greatly reduced, indicating that a considerable increase of rigidity had resulted from the flexion strain applied. It may be considered by some that in actual work railway axles never receive flexion strains of the nature of those adopted in these experiments. There is no doubt, however, that in practical experience axles are frequently subjected to flexion strains of a more or less severe character, and that within certain limits they are not unfrequently strained in that manner.

Mr. Druitt Halpin, M.Inst.C.E., has referred to instances of axles deflecting when running under the strain of loaded wagons, and during submission to the ordinary shocks of the permanent way.* Mr. W. Worby Beaumont, M.Inst.C.E., has also indicated that, "When a train was running, the wheels were lifted up and dropped down again on the very many irregularities of the line at a velocity which induced severe shocks. The velocity at which impact shocks were transmitted through the wheels to the axle was not simply that of gravity or that of the velocity of the train, but very many of the shocks were thus transmitted at the velocity of recoil of a loaded spring, which was probably as much as 1300 feet per second."†

It is certain that axles suffer from abnormally severe flexion-shocks and strains under certain accidental conditions. It is, therefore, most desirable that the material of which they are constructed should, in the first instance, be sufficiently rigid for the practical wear and tear of running; but, at the same time, an excess of primary or initial rigidity should be avoided, otherwise there is considerable danger of sudden fracture from concussional vibration, or the deterioration of fatigue. It is also further desirable that a material should be employed whose rigidity does not excessively increase under the cumulative influence of repeated heavy concussional strain.

Mr. Clement E. Stretton, C.E., has observed: "The advocates of steel axles frequently assert that the matter is simply one of 'strength,' and that as steel is stronger than iron, it must be better for use in axles; but the author contends that very many other matters have to be considered besides the mere tensile strength of iron and steel. An axle may be too stiff and too strong, and this extra stiffness or rigidity causes extra strain and shock to be thrown upon it, which ultimately ends in its failure. It is not so much a question of what is sometimes called 'strength' as of capability to resist strains. It is a well known fact that some straight axles have been made too rigid, and they have broken in consequence."

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* Trans. Soc. Engineers, 1879, p. 175.

† Ibid., p. 173..

Effect of Torsional Strain on the Rigidity and Physical Properties of Railway Axles.

Set IX.—The experiments under this division were conducted on wrought-iron Siemens-steel, and Bessemer-steel axles as follows.

Two adjacent portions were turned out from each axle examined; one portion, called in Set IX., Table X., "unstrained portion," was tested forthwith in the ordinary manner, with the results on Set IX., Table X. The other piece, designated "strained portion" on Set IX., Table X., was turned to the sizes shown on Fig. 3. Each of these latter pieces were then submitted to the strain produced by the relative angles of torsion given on Set IX., Table X. The pieces under examination were then each afterwards turned down to the dimensions as shown on Fig. 4, and tested to destruction in the tensile testing machine.

The results are given in detail on Table X., and clearly indicate an increase of rigidity in railway axles resulting from torsional strain, and a corresponding reduction of elongation in the metal, varying according to the angle of torsion employed in the experiments given on this Table X. The author has great faith in full-sized scale experiments, and it would have been desirable if in these experiments each axle, as a whole, could have been submitted to the strain represented by the respective angles of torsion; but the author could not find an apparatus of sufficient size or power to exert the necessary enormous torsional strain required to twist the full-sized axle, and it was beyond his means to have such a special apparatus constructed. A sufficient indication is however obtained, by the experiments now recorded, of the deleterious influence of torsional strain in increasing the rigidity and reducing the elongation of railway axles submitted to this class of strain. The damaging effect of torsional strain on railway axles, is perhaps more clearly indicated by the enormous reduction of elongation produced by this class of strain, see results on Table X. It is true that in the experiments of this research the stresses applied were abnormally severe, exceeding the elastic limit, and probably beyond anything that might occur in actual practice, nevertheless they afford an indication of the damage that torsional strain sets up in metals, and the results of some recent accidents afford accentuation to the results of the experiments. A dangerous stress is undoubtedly set up in railway axles on rounding curves, arising from the intermittent torsional strains to which they are, under such circumstances, subjected. In proof of this, reference may be made to the following typical accidents, which have, amongst others, recently occurred in actual practice, viz. :—

1. To the fracture of the driving Siemens-steel crank axle of a fast express passenger train, which snapped whilst running at high speed, on a 40-chain curve, this fracture causing the frightful calamity at Bullhouse, near Penistone, on July 16, 1884, attended with serious loss of life.

2. To the sudden snapping into four pieces of the leading Bessemer-steel axle of a fish van, attached to an express passenger train, near Winwick Junction, on September 20, 1888, whilst the train was proceeding at full speed over the following curves: "An 80-chain curve to the west, then straight for about 105 yards; then upon a 40-chain curve to the west for about 83 yards, then straight for about 105 yards; then upon a 20-chain curve to the west for about 100 yards, to the trailing points of the junction of the up fast and up slow lines; and then upon a 70-chain curve to the west."

3. To a case of derailment of a passenger train, attended with loss of life, and damage to rolling stock, which occurred at Penistone, March 30, 1889. This accident was caused by the instantaneous fracture into several pieces of the straight leading cast-steel axle of the engine, whilst the train was rounding a curve of about 48 chains radius.

4. Attention may be called to the fracture of the steel crank axle of a passenger train at Larbert Junction, on the Caledonian and North British Railways, on August 24, 1885. At the place of this accident there is a curve westward of about 20 chains radius.

5. Reference may also be made to the fracture of the engine axle of a passenger train from Barnsley to Stairfoot, which broke immediately after leaving the short and sharp curve at Quarry Junction.

6. To the fracture of the leading tender axle of a goods engine, which broke on September 7, 1887, in the neighbourhood of Wortley, near Sheffield, whilst the train was rounding a sharp curve.

In connection with the accident which occurred at the

Saint Vigean's Junction, near Arbroath, on the Dundee and Arbroath Joint Railway, Major Marindin stated, "This is not the only place where curves of such small radius ought to be enlarged. It is impossible to get safety with rigid wheel bases on such curves." Further instances of the liability to sudden fracture of steel railway axles—the danger having probably been accentuated by the alternating torsional strains set up previously by the curves of the road—are afforded by the fracture of the Siemens-steel axle of the engine of the London and Scotland passenger train at Kirtle Bridge, near Carlisle, January 8, 1891; the fracture of the Siemens-steel axle of the engine of a passenger train at Abington, Caledonian Railway, February 4, 1891; the appalling accident on the Canadian Pacific Railway, near Schrieber, on February 5, 1891, caused by the fracture of the Siemens-steel axle (of British manufacture) of a sleeping car; the fracture of a steel straight-driving axle on the engine of the Manchester and Liverpool passenger train near Warrington, in March 1891; the fracture of the steel crank axle of the engine of the "Flying Dutchman" express near Reading, May 16, 1891; the fracture of the Siemens-steel crank axle of the engine of an excursion train at Tallington, Great Northern Railway, August 1892; the fracture of a steel wagon axle at Wortley, on November 28, 1892; the fracture of a Bessemer-steel van axle at Crewe, on January 25, 1894.

Additional information of the tendency of steel axles to sudden fracture, apparently from the brittleness produced from the deterioration of fatigue, is afforded by the unsatisfactory experience with steel axles on the railways of India,* and also on the railways of Australia.

Reference may also be made, in connection with this subject, to the following recent breakages of propeller shafts, which further illustrate the danger to steel shafts from torsional strains, viz., the sudden fracture of the propeller shaft of the s.s. *Dolphin*, United States Navy, which broke on the trial trip; to the sudden fracture of the steel propeller shaft of the s.s. *City of Paris*; and also to the serious accident which occurred in mid-ocean, on December 23, 1892, to the celebrated Cunard steamer the *Umbria*, caused by the sudden fracture of the steel screw shaft. The Red Star Line mail and passenger steamer *Nordland*, 3346 tons, with 151 passengers aboard, was disabled on December 22, 1892, on a voyage from New York to Antwerp, by the fracture of the main propeller shaft, which broke about six feet from the propeller, smashing part of the tube and stay plates, and causing the after peak to fill with water.

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* See remarks hereon by Sir Alexander M. Rendel, K.C.I.E., M.A., M. Inst. C.E., 'The Engineer,' September 19, 1890.

Another accident of a similar nature occurred on December 26, 1892, to the North German Lloyd Royal Mail steamer *Spree,* bound from Southampton to New York (with 506 passengers aboard). This accident was caused by the sudden fracture of the main shaft, which, in breaking, apparently pierced through the bottom of the vessel, filling her after-compartment with water. An accident also recently occurred to the large ocean s.s. *City of Pekin,* which was disabled in the midst of the Pacific Ocean, on a voyage from Yokohama, by the sudden fracture of her propeller shaft.

Some further idea of the magnitude of the danger arising from the liability of steel propeller shafts snapping suddenly under torsional strain will be obtained on reference to the information given by Sir Benjamin B. Baker, F.R.S., M.Inst.C.E.,* who has stated that during the three years from 1882 to 1885 no less than 228 large steamers were disabled in consequence of broken shafts, and that the longest life of these steel shafts cannot well be put at more than three or four years. Another instance of the liability to sudden fracture of propeller shafts from torsional strain is found in the breakdown, in August 1893, of the s.s. *Sarnia.*

These instances prove from actual experience that large steel shafts, however well they may be constructed, are rendered liable to sudden and accidental fracture from the deterioration of the metal, consequent on the heavy and repeated torsional and other stresses to which they are perpetually exposed in course of their ordinary wear and tear. The intermittent torsional strains set up in a railway axle when rounding curves† is probably the worst disruptive force with which a railway axle has to contend. Torsional and flexion stresses are practically also the worst enemies to marine and driving shafts. Railway axles and shafts are exposed to the greatest danger when there is an abnormal combination of flexion and torsion strain acting upon them. This constant stress doubtless sets up internal molecular vibration, which, in course of time, induces the deterioration of initial resistance to stress, which ultimately terminates in the fracture of the metal. Indeed, few engineers would be found willing to underrate these potent factors in the destruction of both crank and straight axles and marine or other shafts. Further information as to accidents of this class will be found on reference to a work on 'Iron or Steel Railway Axles,' by the author.

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* Report of the British Association, 1885, pp. 1185 and 1186.

† See particulars in a paper on this subject in 'The Engineer,' June 20, 1890, on 'The Fracture of Steel Axles on Rounding Curves,' by Mr. Thomas Andrews, F.R.S., M. Inst. C.E.

It may be contended that axles and shafts, in actual practice, are not liable to be exposed to torsional or other strains exceeding the elastic limit; it would be unwise, however, to place too much reliance on this view. Strains from external causes are not unfrequently augmented by internal stresses of considerable magnitude; indeed, at the International Congress at Chicago, 1893, Sir Benjamin Baker has recently shown that "Many parts are subjected to internal stresses quite up to, if not exceeding, the elastic limit. Stresses as great as 22,000 lb. to the square inch occur from this cause, and it is a dangerous source of fractures."* Sir Benjamin Baker further remarked, as a result of his examination of gun steel, and in allusion to initial sources of weakness in steel arising from internal stresses, that "he had found the fractures beginning in the middle of the thickness of the metal and extending to the surface."†

Dr. Dudley, of the Pennsylvania Railroad, has also recently found, in testing a number of steel crank pins, that one side of these crank pins gave a tensile strength of about 39·29 tons per square inch, and an elongation of 22 per cent., whereas the opposite side of the same forging showed a tensile strength of about 47·32 tons per square inch and only 14 per cent. elongation, so that a considerable amount of internal stress must have been present in these forgings. Further, nine tensile tests of a steel tender axle, the samples being taken from each end and the middle of the same axle, showed a tensile strength varying from 37·88 tons per square inch to 40·67 tons per square inch; the elongation, in a length of 10 inches, varying from 7·3 per cent. to 11 per cent., the latter fact indicating a diversity of about 50 per cent. in the physical properties of the same steel axle. Moreover, the Bessemer-steel axle of the fish van, which suddenly snapped into four pieces near Winwick Junction, on September 20, 1888, whilst showing the high tensile strength of 42·52 tons per square inch, yielded only the very low elongation of 1·5 per cent., indicating that steel axles are liable to lose the property of elongation and to become brittle.

EFFECT OF TENSILE STRAIN ON THE RIGIDITY AND PHYSICAL PROPERTIES OF RAILWAY AXLES.

Set X.—The observations in this section of the research were made as follows. Two adjacent pieces were cut from axle A. One piece was tested in the ordinary manner in the tensile testing apparatus, to ascertain the normal physical properties of the axle; the results are given on Set X., Table XI.

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* 'The Engineer,' September 1, 1893, p. 217.

† Ibid.

The other piece from the same axle, and of the same dimensions as shown on Fig. 5, was then submitted to gradually increasing strains until a slight and previously required elongation was produced (see Set X., Table XI.). The metal was then released from stress, and allowed to rest for 48 hours; the piece was afterwards machined to the dimensions given on Fig. 5, and then tested in the tensile apparatus, with the results given on Set X., Table XI.

The results of these experiments showed that the rigidity of the metal was increased 2·66 per cent., and its elongation reduced 36 per cent., under the conditions stated.

Test pieces were cut in a similar manner from axle B. One was tested in the ordinary manner, for purposes of comparison, the other one was submitted to a gradually increasing series of tension strains, and intervals of rest allowed between each successive increase of stress. The piece was then tested to destruction, without further alteration of form. The readings, taken from the original dimensions previous to the application of any strain, indicated that no material alteration of the physical properties of the metal had occurred traceable to the effect of the small intervals of rest. It is, however, probable that with more prolonged intervals of rest a measurable effect might have been produced, after the manner referred to by Styffe: "Sometimes we have even found that the limit of elasticity in stretched bars has been perceptibly raised by merely allowing the bar to remain at rest for several days after stretching."* Again, "During a considerable time after the stretching, the stretching point goes on rising, and with it the tensile strength."† "This strengthening during rest was, according to Bauschinger, discovered by Wöhler; Styffe certainly knew it in 1869; Thurston and Beardslee rediscovered it independently in 1873."‡ Beardslee found that 42 days' rest gave an increase of tensile strength of about 15 per cent., and six months' rest yielded an increase of strength of near 18 per cent.

In the experiment on axle C two test pieces were cut from the axle, and one tested to destruction ordinarily for comparative purposes, and the other received a stress of 31¼ tons, and an interval of rest of eleven days was allowed, when the piece was tested to destruction. In these experiments the original diameter of the test piece, previous to the application of a stress of 31¼ tons, was 1½ inch thick; both test pieces were, however, ultimately turned down to 1⅛ inch diameter between datum points 2 inches apart, and finally tested at 1⅛ inch diameter. The results are given on Set X., Table XI., and show that, under the conditions thereon recorded, the rigidity of the metal had increased 18·2 per cent., and that its elongation had been reduced 20·95 per cent. The results of the experiments of Set X., therefore, indicate that a tensile stress which an axle may experience, however slightly in excess of its elastic limit, produces a very considerable alteration of its normal physical properties, greatly increasing its rigidity and liability to sudden fracture. Whilst ordinarily the stress on axles will not exceed the elastic limit, yet it would be unwise to infer that in actual practice axles will be exonerated from strains closely approaching to, or even in some instances in excess of the elastic limit of the metal.

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* 'Iron and Steel,' Styffe, Sandberg, p. 109.

† 'Metallurgy of Steel,' by Henry M. Howe, M.A., p. 213.

‡ Ibid.

EFFECT OF HEAVY IMPACT STRAIN ON THE RIGIDITY OF RAILWAY AXLES.

This series of experiments were made to obtain accurate information as to the increase of rigidity, or reduction of flexibility, which the author has observed when railway axles of either wrought iron or steel are exposed to repeated concussional shocks. It also seemed desirable to ascertain the relative extent to which wrought-iron axles, Siemens-steel axles, and Bessemer-steel axles were respectively affected by stress of this nature.

Set XI., Tables XII., XIII. and *XIV.*, contain the results of the tensile tests of the axles tested under impact strain, which afford some indication of the physical properties of the axles. There is no feature in connection with these tests calling for special remark. It may perhaps, however, be observed that a wider diversity of tensile strength, or inherent rigidity, was noticeable in the series of Bessemer-steel axles, this variation ranging from a breaking strain of 26·16 tons per square inch to one of 40 tons per square inch. A greater general uniformity of normal rigidity obtained in the Siemens-steel axles and the wrought-iron axles. In the former the lowest strength recorded was 28·40 tons per square inch, and the highest was 38·60 tons per square inch. The series of wrought-iron axles also manifested a general uniformity of normal rigidity, ranging between a breaking strain of 20·52 tons and 22·74 tons per square inch. In practice the author generally finds this to be the case, wrought-iron and Siemens-steel axles yielding more even results with respect to their respective tensile strengths.

Set XII., Tables XV. and *XVI.*—This series contains the results of numerous experiments on the influence of impact strain on 62 wrought-iron railway axles, at the various temperatures stated on the tables. Under the conditions of experimentation it was observed that, at the temperature of 212° F., or 100° C., the total average increase in the rigidity of the axles resulting from repeated impact strain was about 39·71 per cent. At the temperature of 100° F., or 38° C., the total average increase of rigidity, under similar conditions, except that of temperature, was considerably reduced, being not more than 10·69 per cent. At the normal temperature of about 50° F., or 10° C., the total increase of rigidity consequent on repeated heavy concussional strain was found to be 5·60 per cent., under the conditions given on Set XII. Table XVI.

Set XII., Table XVII.—In this set are the results of a series of tests showing the effect of continued impact strain on fifty Siemens-steel railway axles, at the normal temperature of 50° F., or 10° C. These observations indicate a total increase of rigidity in Siemens-steel axles resulting from repeated heavy impact strains, under the conditions stated, of 9·64 per cent.

Set XII., Table XVIII.—This table contains the record of the effects of repeated impact strain on the rigidity of fifty Bessemer-steel railway axles, at the normal temperature of 50° F., or 10° C. The results show a total increase of rigidity in Bessemer-steel axles, traceable to the repeated heavy concussions, of 10·27 per cent.

The comparative results of such a large number of experiments may be regarded as having an important practical bearing, and as affording an approximate indication of the relative extent to which wrought iron and steel axles increase in rigidity under concussional strain.

Contrasting the comparative results obtained under similar conditions with wrought-iron axles, Siemens-steel axles, and Bessemer-steel axles, it will be noticed that under the conditions of experimentation the increase of rigidity, owing to repeated concussion, was in wrought-iron axles, 5·60 per cent.; in Siemens-steel axles, 9·64 per cent.; in Bessemer-steel axles, 10·27 per cent. These results indicate that steel axles increase in rigidity nearly double the extent of wrought-iron axles when under conditions of heavy concussional strain.

Moreover, it was noticed that the variation in the extent of the increase of rigidity under impact stress was greater in both the Siemens-steel and Bessemer-steel axles, than amongst the wrought-iron axles, which latter, compared axle for axle at normal temperature, scarcely showed any variation in the relative increase of rigidity under impact strain. The divergence in the results of the Bessemer-steel axles ranged from 1·75 per cent. to 19·05 per cent. In the Siemens-steel axles the variation ranged from 2·50 per cent. to 20 per cent., whereas in the case of the wrought-iron axles examined at the normal temperature of 50° F., or 10° C., there was only a very slight variation between the individual axles experimented upon. This circumstance is illustrated by Fig. 7.

A reference to the results on Set XII., Tables XVI., XVII. and XVIII., shows that the extent of the first deflection in a series of 50 wrought-iron axles, 4½ inches each diameter in the middle, averaged 4·237 inches; a series of eighteen Siemens-steel axles of the same dimensions yielded an average first deflection of 3·785 inches; whereas a comparative series of 32 Bessemer-steel axles showed a first deflection which averaged only 3·443 inches. These results afford an indication of the relative initial rigidity at normal temperature of railway axles made by the respective processes referred to above. Bessemer-steel axles are thus shown to manifest the greatest rigidity, a circumstance unfavourable to their use when compared with wrought-iron and Siemens-steel axles.

MINIMUM FLEXION RESISTANCE-POINT IN RAILWAY AXLES, AND THE EFFECT OF TEMPERATURE ON THE FLEXION ENDURANCE OF AXLES.

In addition to other results recorded in this paper, another circumstance of considerable practical importance brought to light by these experiments was the great influence varying temperature exerted on the total ultimate resisting strength of railway axles to flexion, as shown by the following statement of facts observed :—

TABLE XIX.

Number of Axles Fractured by Slow Flexion.	Temperature of Axle in Degrees.		Average Total Number of Flexions previous to Fracture.	Total Average Force in Tons producing Fracture.	Total Average Increase of Rigidity per cent.	Maximum Increase of Rigidity observed per cent.
	Cent.	Fahr.				
12	−18	0 (zero)	18	1008·47	10·34	16·68
10	10	50	..	..	13·20	18·74
12	38	100	18	971·92	15·73	24·49
12	100	212	10	524·25	16·14	24·75
12	300	572	6	312·66	18·76	26·41
12	450	842	10	538·63	18·06	28·76
12	600	1112	23·5	143·96	123·16	199·65

From the above observations it will be seen that the axles exhibited the greatest endurance of slow flexion strain at temperatures up to 100° F., and that there was a minimum flexion resistance point at 572° F., or 300° C.

At the temperature of 212° F., or 100° C., the ultimate endurance of the axles to flexion stress was reduced to nearly one-half of that obtaining at ordinary temperatures, whereas, at 572° F., or 300° C., the resistance to strain was only about one-third of the endurance manifested at temperatures between zero (0°) F. and 100° F. (see Fig. 8). This fact indicates that the temperature of 572° F., or 300 C., is the one at which railway axles are most liable to sudden fracture when under flexion strain. In actual practice this temperature is sometimes reached through the accidental heating of the journals, and 572° F., or 300° C., must therefore be regarded as a critical point of weakness in railway axles. The sudden lowering of vital energy at this temperature in railway axles may probably account for some fractures of axles, whose sudden destruction has been hitherto involved in some degree of obscurity.

In his research on 'Effects of Temperature on the Strength of Railway Axles,' Parts I., II. and III., and in his investigation on 'Effects of Chilling on the Impact Resistance of Metals,'* the author has previously demonstrated that a danger point exists in railway axles under impact stress at the low temperature of zero (0°) F. He has now been able to indicate the existence of a second and perhaps more critical danger point in axles under flexion stress at the higher temperatures referred to above.

The danger referred to above would be intensified by frequent alternations of temperature in an axle. This circumstance would tend to induce internal molecular friction, and hence internal stress in the metal, which would intensify the deterioration due to the fatigue of vibration. In some countries there are considerable diurnal variations of temperature, apart from the wider range of the winter and summer climate; and the combined effect of these constantly repeated changes is, in the aggregate, not inconsiderable in setting up internal strains in iron and steel axles, the latter being, from the nature of the metal, more sensitive to the influence of change of temperature.

The whole of the experiments of this research coincide in indicating an increase of rigidity in railway axles under the influence of the varied kinds of stress and strain applied (beyond the elastic limit), the extent of the increase of rigidity varying according to the nature of the metal, the conditions of temperature, and the species of strain; the effects of strain being similar, whether produced by slow flexion, impact shocks, torsional, tensile, or other strains. The results also show that the greater the strain to which the metal was submitted, the greater was the increase of rigidity and decrease of elongation, and consequent deterioration of its physical properties. Steel axles, both Bessemer and Siemens, have been shown, in course of this research, to increase in rigidity under concussional shocks more than wrought-iron ones.

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* Min. Proc. Inst. C.E., vols. lxxxvii., xciv., cv. and ciii.

The observance of the fact that a marked decrease of resistance to flexion stress was manifested in railway axles at the temperature of 212° F., or 100° C., and also a similar most extensive reduction of flexion endurance at the temperature of 572° F., or 300° C., was a further interesting and important result of this research. This fact affords a strong indication of the increased danger to axles arising from overheated necks during running.

The accompanying photographic plates illustrate the combined effect of temperature and strain on the nature of the metal, tested under the diverse temperature conditions recorded in Set II., Table III., and Set V., Table VI.

The present research has been beset with many difficulties, and it has been a laborious investigation. Some idea of this will be conveyed when it is understood that a total of 284 wrought-iron and various steel railway axles, of a total weight of about 57 tons, have been examined to destruction in course of the various tests and experiments required to complete the enquiry.

APPENDIX.

The following particulars respecting the fractured steel shaft of the s.s. *Dolphin*, United States Navy, which broke on the trial trip, also indicates that a considerable want of homogeneity is liable to exist in these large steel forgings, which tends to induce initial weakness when they are subjected to external stress. Professor W. C. Unwin, F.R.S., M.Inst.C.E., remarks in his valuable work, 'On the Testing of Materials of Construction,' p. 290, "A steel propeller shaft of the United States despatch boat *Dolphin* broke on the trial trip, and test bars cut from the shaft gave the following results":—

—	Elastic Limit.	Tenacity.	Elongation.
	tons per sq. in.	tons per sq. in.	per cent.
From centre of shaft	15·2	24·1	2
From surface of shaft	14·3	35·7	18

The lack of homogeneity in steel, productive of internal tension and stress in steel axles and forgings, has been shown by chemical tests.

An analysis of the top of a steel ingot showed combined carbon 0·760 per cent., but the bottom of the same ingot showed only 0·350 per cent. of combined carbon. The sulphur in the top portion of the ingot was 0·187 per cent., but at the lower part of the ingot it was only 0·044 per cent. The phosphorus in the portion cut from the upper part of the ingot was 0·191 per cent., whereas in the lower part of the ingot the phosphorus was only 0·044 per cent. Sometimes, also, the outside edge of large steel ingots used for shafts and forgings is found to be very hard and contains a higher percentage of combined carbon than the interior.

In another instance, six samples taken from the top of a steel ingot, and six samples from the bottom of the same ingot, the samples being taken at equal distances from the outside to the centre of the ingot, showed a diversity in the percentage of combined carbon of about 70 per cent.; the percentage of sulphur varying from 0·032 on the outside of the ingot to as much as 0·187 in the centre, the proportion of phosphorus showing similar variable results.

There is also a tendency in straight steel axles to suddenly fracture simultaneously into several pieces, as exemplified by the fracture into four pieces of the Bessemer-steel axle of the fish van in the Winwick Junction accident, September 20, 1888, and again in the case of the broken straight cast-steel engine axle in the Penistone accident, March 30, 1889, which fractured into three pieces. This circumstance affords a further indication of the non-homogeneity of steel axles, and the deterioration of the metal by the fatigue of wear and tear, and of the existence of unequal internal stresses in different parts of the axle, inducing fractures in several places at the same time.

Another example of the presence of internal strain in steel forgings will be seen on reference to the illustrated letter thereon, by "Marine," in the 'Engineer,' October 17, 1890. Indeed, it appears to the author that we are in comparative ignorance of the whole subject of the initial internal stress sometimes obtaining in different parts of the same steel axle or shaft. It is a subject of such importance as to demand careful investigation in the manner indicated by Dr. Dudley's tests, or by other methods.

Considerable internal strains have also been found to exist in large masses of steel, such as armour plates, and these plates have been known to suddenly fracture both before and after fixing on the ship's side, from no apparent causes except those referable to internal initial stress. Examples of this class of fracture were afforded by the failure in this manner of many of the steel armour plates for the French war vessel, the *Terrible.* Eighteen out of a total of 90 plates were rejected for cracks resulting from internal strain. Further particulars relating to failures of steel plates from initial stress will be found on reference to the 'Engineer,' April 15, 1887, and to the 'American Army and Navy Journal,' March 12, 1887. The author has cognisance of cases of failures of heavy guns, apparently traceable to no other cause than initial weakness, consequent on internal strains in the steel, and Sir Benjamin B. Baker has also alluded to the extent of these deleterious defects in gun steel in his remarks previously quoted.

TABLE I.

Total Number of Railway Axles on the Railways of Various Countries, and the Annual Average Tonnage carried per Wagon Axle, exclusive of the Weight of the Vehicle.

Railways of	Total Mileage of Railways in the World.	Approximate Number of Locomotive Engine Axles.	Approximate Number of Railway Carriage Axles.	Approximate Number of Railway Wagon Axles.	Total Annual Tonnage carried.	Average Approximate Weight in Tons carried by each Wagon Axle per Annum.
United Kingdom	20,073	48,711	127,202	1,081,156	303,119,427	280
Canada	15,683	5,313	5,045	98,712	18,554,883	188
South Australia ..	1,756	606	750	10,320	1,303,900	126
Tasmania	399	75	160	1,010	110,949	110
New South Wales	2,182	1,317	2,660	18,608	3,788,950	204
Victoria	2,650½	2,275	2,764	16,070	4,425,609	275
India	16,996	11,241	25,782	141,336	22,612,718	160
U.S. of America ..	171,000	87,108	64,162	2,085,780	539,639,583	259
Austria-Hungary	16,712	14,346	23,990	216,754	86,989,769	401
German Empire ..	25,958	39,321	60,962	525,176	199,507,000	380
Russia in Europe	17,594	20,412	19,195	283,796	67,473,000	238
Denmark	1,247	Probable total number of axles of various kinds on the railways of these thirteen countries: 33,341	48,271	650,110	1,471,201	277
Norway	971				1,425,413	
Sweden	5,012				8,486,694	
Holland	1,705				8,294,632	
Belgium	2,830				43,073,919	
France	20,833				87,043,706	
Italy	7,817				15,051,341	
Portugal	1,334				1,049,801	
Switzerland ..	1,980				8,629,307	
Egypt	1,127				1,695,875	
Mexico	6,266				875,894	
Brazil	5,900				1,820,106	
Japan	1,128				1,162,749	
Additional total mileage of railways in all the other fifty countries of the world possessing railways	33,681½	..	..	..	..	..
Totals	382,835	264,066	380,943	5,128,828	1,427,606,426	278

The above statistics afford a fairly cosmopolitan approximation of the vast total number of railway axles in use in various parts of the world, and of the enormous weight of the traffic carried by them. The figures do not, however, fully represent the total number of axles in work throughout the world, as statistical information is not obtainable from some countries.

The information on which the above estimates are based is derived from the Official Reports on the railways of the respective countries, and from other reliable private sources of information, which the author has carefully studied, relating to the 74 nations or countries in the world possessing railways.

SET I.

TABLE II.—Increased Rigidity of Railway Axles under Flexion Strain.

Temperature of Axles during Experiment, 50° Fahrenheit = 10° Centigrade.
Deflection between Bearings at each bending, 2 inches.

Number of Bendings.	Force in Tons required at each Pressure to produce Flexion of Axles.										Average of Experiments.	Total Increase of Rigidity per cent.
	Series A.		Series B.		Series C.		Series D.		Series E.			
	Axle P. 3.	Axle P. 4.	Axle P. 5.	Axle P. 6.	Axle P. 1.	Axle P. 2.	Axle P. 7.	Axle P. 8.	Axle P. 9.	Axle P. 10.		
1	45·24	45·24	45·24	45·24	45·24	45·24	45·24	45·24	45·24	45·24	45·24	..
2	..	..	50·89	50·89	45·24	50·89	50·89	50·89	50·89	50·89	50·19	10·94
3	..	..	..	..	50·89	50·89	50·89	50·89	50·89	50·89	50·89	12·49
4	..	..	..	..	50·89	50 89	50·89	50·89	50·89	50·89	50·89	12·49
5	..	..	..	..	..	..	50·89	50·89	50·89	50·89	50·89	12·49
6	..	..	..	..	..	..	50·89	50·89	50·89	50·89	50·89	12·49
7	..	..	..	..	..	..	50·89	56·55	50·89	50·89	52·31	15·63
8	..	..	..	..	..	..	50·89	50·89	50·89	50·89	50·89	12·49
9	..	..	..	..	..	..	..	..	50·89	50·89	50·89	12·49
10	..	..	..	..	..	..	..	..	50·89	50·89	50·89	12·49
11	..	..	..	..	..	..	..	..	56·55	50·89	53·72	18·74
12	..	..	..	..	..	..	..	..	50·89	50·89	50·89	12·49
Total Force applied in Tons	45·24	45·24	96·13	96·13	192·27	197·92	401·50	407·16	610·74	605·08	..	13·20

Each axle received the number of flexions stated, and required the Force in Tons to bend it given in the Tables, but none of the above axles were tested to destruction.

SET I.—continued.

TABLE II. (*continued*).—Increased Rigidity of Axles under Flexion Strain.

Temperature of Axles during Experiment, 50° Fahrenheit = 10° Centigrade.
Deflection between Bearings at each bending, 2 inches.

No. of Bendings.	Bessemer Steel Axle.		Siemens Steel Axle.		Siemens Steel Axle.	
	Force in Tons required at each Pressure to produce Flexion of Axles.	Increase of Rigidity per cent.	Force in Tons required at each Pressure to produce Flexion of Axles.	Increase of Rigidity per cent.	Force in Tons required at each Pressure to produce Flexion of Axles.	Increase of Rigidity per cent.
1	79·17	..	79·17	..	67·86	..
2	73·51	..	79·17	..	67·86	..
3	90·49	14·30	90·49	14·30	79·17	16·67
4	79·17	..	79·17	..	67·86	..
5	96·13	21·42	90·49	14·30	79·17	16·67
6	79·17	..	79·17	..	67·86	..
7	101·79	28·57	96·13	21·42	79·17	16·67
8	84·82	7·14	79·17	..	67·86	..
Average	..	17·86	..	16·67	..	16·67

SET II.

TABLE III.—Increased Rigidity of Railway Axles under Flexion Strain.

Temperature of Axles during Experiment, 0° Fahrenheit = – 18° Centigrade.
Deflection between Bearings at each bending, 2 inches.

Number of Bendings.	Force in Tons required at each Pressure to produce Flexion of Axles.												Average of 12 Experiments.	Total Increase of Rigidity per cent.
	Axle No. 13.	Axle No. 14.	Axle No. 15.	Axle No. 16.	Axle No. 17.	Axle No. 18.	Axle No. 19.	Axle No. 20.	Axle No. 21.	Axle No. 22.	Axle No. 23.	Axle No. 24.		
1	50·89	50·89	50·89	50·89	50·89	50·89	50·89	50·89	50·89	50·89	50·89	50·89	50·89	..
2	56·55	56·55	53·72	53·72	53·72	53·72	53·72	53·72	53·72	53·72	53·72	53·72	54·19	6·48
3	56·55	56·55	56·55	56·55	56·55	56·55	56·55	56·55	56·55	56·55	56·55	56·55	56·55	11·12
4	53·72	53·72	53·72	53·72	53·72	53·72	53·72	53·72	53·72	53·72	53·72	53·72	53·72	5·56
5	56·55	59·38	59·38	59·38	59·38	59·38	59·38	59·38	59·38	59·38	59·38	59·38	59·14	16·21
6	53·72	53·72	53·72	53·72	53·72	53·72	56·55	53·72	53·72	53·72	56·55	53·72	54·19	6·48
7	56·55	59·38	59·38	59·38	59·38	59·38	..	59·38	59·38	59·38	59·38	59·38	59·12	16·17
8	53·72	56·55	53·72	53·72	53·72	53·72	..	56·55	53·72	53·72	..	53·72	54·29	6·68
9	59·38	59·38	59·38	59·38	59·38	59·38	..	59·38	59·38	59·38	..	59·38	59·38	16·68
10	53·72	56·55	53·72	56·55	53·72	53·72	..	53·72	56·55	53·72	..	53·72	54·57	7·23
11	56·55	48·07	59·38	59·38	59·38	59·38	..	59·38	59·38	59·38	..	59·38	57·97	13·91
12	53·72	56·55	56·55	53·72	53·72	53·72	..	53·72	53·72	56·55	..	53·72	54·57	7·23
	*	*	*	*	*	*		*	*	*		*	*	
Total Force applied in Tons	992·43	944·38	955·69	1413·75	1671·04	1012·24	330·81	729·49	786·04	1464·64	390·19	1410·92	1008·47	10·34
Total number of Flexions before fracture	18	17	17	25	30	18	6	13	14	26	7	25	18	..

* The bending of the axle was continued until it broke at the number of flexions stated, and having endured the Force in Tons given in the totals at the foot of each record in the above Table.

SET III.

TABLE IV.—INCREASED RIGIDITY OF RAILWAY AXLES UNDER FLEXION STRAIN.

Temperature of Axles during Experiment = 100° Fahrenheit = 38° Centigrade.
Deflection between Bearings at each bending, 2 inches.

Number of Bendings.	Force in Tons required at each Pressure to produce Flexion of Axles.												Average of 12 Experiments.	Total Increase of Rigidity per cent.
	Axle No. 25.	Axle No. 26.	Axle No. 27.	Axle No. 28.	Axle No. 29.	Axle No. 30.	Axle No. 31.	Axle No. 32.	Axle No. 33.	Axle No. 34.	Axle No. 35.	Axle No. 36.		
1	45·24	45·24	45·24	45·24	50·89	50·89	45·24	45·24	45·24	45·24	45·24	45·24	46·18	..
2	48·07	48·07	48·07	48·07	53·72	53·72	50·89	48·07	48·07	45·24	48·07	48·07	49·01	6·13
3	50·89	53·72	53·72	53·72	56·55	56·55	53·72	53·72	53·72	50·89	53·72	53·72	53·72	16·33
4	48·07	48·07	50·89	50·89	53·72	50·89	50·89	50·89	50·89	48·07	48·07	50·89	50·18	8·66
5	53·72	56·55	53·72	56·55	59·38	59·38	56·55	53·72	56·55	56·55	56·55	56·55	56·31	21·94
6	50·89	50·89	50·89	50·89	56·55	53·72	50·89	50·89	50·89	50·89	50·89	50·89	51·60	11·74
7	56·55	56·55	53·72	56·55	62·20	59·38	56·55	56·55	56·55	56·55	56·55	56·55	57·02	23·47
8	50·89	50·89	50·89	50·89	56·55	53·72	50·89	50·89	50·89	50·89	50·89	50·89	51·60	11·74
9	56·55	56·55	56·55	56·55	59·38	62·20	56·55	56·55	56·55	56·55	56·55	56·55	57·26	23·99
10	50·89	50·89	50·89	50·89	56·55	53·72	50·89	50·89	50·89	50·89	50·89	50·89	51·60	11·74
11	56·55	56·55	56·55	56·55	62·20	62·20	56·55	56·55	56·55	56·55	56·55	56·55	57·49	24·49
12	50·89 *	53·72 *	50·89 *	53·72 *	56·55 *	56·55 *	50·89 *	50·89 *	48·07 *	50·89 *	50·89 *	50·89 *	52·07 *	12·75
Total Force applied in Tons	1000·90	899·12	732·29	1608·79	800·17	969·80	1012·20	1221·43	839·74	1212·95	681·41	684·23	971·92	15·73
Total number of Flexions before fracture	19	17	14	30	14	17	19	23	16	23	13	13	18	..

* The bending of the axle was continued until it broke at the number of flexions stated, and having endured the Force in Tons given in the totals at the foot of each record in the above Table.

SET IV.

TABLE V.—Increased Rigidity of Railway Axles under Flexion Strain.

Temperature of Axles during Experiment, 212° Fahrenheit = 100° Centigrade.
Deflection between Bearings at each bending, 2 inches.

Number of Bendings.	Force of Tons required at each Pressure to produce Flexion of Axles.												Average of 12 Experiments.	Total Increase of Rigidity per cent.
	Axle No. 37.	Axle No. 38.	Axle No. 39.	Axle No. 40.	Axle No. 41.	Axle No. 42.	Axle No. 43.	Axle No. 44.	Axle No. 45.	Axle No. 46.	Axle No. 47.	Axle No. 48.		
1	45·24	45·24	45·24	45·24	45·24	45·24	50·89	50·89	45·24	45·24	45·24	45·24	46·18	..
2	48·07	50·89	48·07	48·07	48·07	45·24	53·72	53·72	48·07	48·07	48·07	48·07	49·01	6·13
3	53·72	53·72	50·89	50·89	53·72	53·72	56·55	56·55	53·72	53·72	53·72	53·72	53·72	16·33
4	50·89	50·89	50·89	50·89	50·89	50·89	53·72	53·72	50·89	50·89	50·89	50·89	51·36	11·22
5	56·55	56·55	53·72	56·55	56·55	56·55	59·38	59·38	56·55	56·55	56·55	56·55	56·79	22·98
6	50·89	50·89	50·89	50·89	50·89	50·89	53·72	53·72	50·89	50·89	50·89	50·89	51·36	11·22
7	56·55	56·55	56·55	56·55	56·55	56 55	59·38	62·20	56·55	56·55	56·55	56·55	57·26	23·99
8	50·89	50·89	50·89	50·89	..	50·89	53·72	56·55	..	50·89	50·89	50·89	51·74	12·04
9	..	56·55	..	56·55	..	56·55	59·38	59·38	..	56·55	59·38	56·55	57·61	24·75
10	..	..	..	50·89	..	..	53·72	..	..	53·72	50·89	50·89	52·02	12·65
11	..	..	..	56·55	..	..	59·38	..	..	56·55	56·55	..	57·26	23·99
12	..	..	..	50·89 *	..	..	53·72 *	..	..	..	50·89 *	..	51·83	12·23
Total Force applied in Tons	412·80	472·17	407·13	678·57	361·91	466·52	729·48	506·11	361·91	579·62	794·50	520·24	524·25	16·14
Total number of Flexions before fracture.	8	9	8	13	7	9	13	9	7	11	15	10	10	..

* The bending of the axle was continued until it broke at the number of flexions stated, and having endured the Force in Tons given in the totals at the foot of each record in the above Table.

SET V.

TABLE VI.—Increased Rigidity of Railway Axles under Flexion Strain.

Temperature of Axles during Experiment, 572° Fahrenheit = 300° Centigrade.
Deflection between Bearings at each bending, 2 inches.

Number of Bendings.	Force in Tons required at each Pressure to produce Flexion of Axles.												Average of 12 Experiments.	Total Increase of Rigidity per cent.
	Axle No. 49.	Axle No. 50.	Axle No. 51.	Axle No. 52.	Axle No. 53.	Axle No. 54.	Axle No. 55.	Axle No. 56.	Axle No. 57.	Axle No. 58.	Axle No. 59.	Axle No. 60.		
1	45·24	45·24	45·24	45·24	45·24	45·24	45·24	45·24	48·07	45·24	45·24	45·24	45·48	..
2	50·89	50·89	50·89	50·89	50·89	50·89	50·89	48·07	50·89	48·07	50·89	50·89	50·42	10·86
3	56·55	56·55	53·72	56·55	53·72	56·55	56·55	53·72	56·55	53·72	56·55	56·55	55·61	22·27
4	53·72	50·89	50·89	50·89	50·89	50·89	50·89	50·89	53·72	50·89	..	50·89	51·40	13·02
5	56·55	56·55	56·55	..	56·55	56·55	56·55	56·55	56·55	56·55	..	56·55	56·55	24·34
6	..	..	50·89	..	..	53·72	50·89	50·89	50·89	50·89	..	50·89	51·29	12·77
7	..	..	..	..	..	59·38	56·55	..	..	56·55	..	..	57·49	26·41
8	..	..	..	..	..	53·72	50·89	..	..	53·72	..	..	52·78	16·07
9	..	..	..	..	..	..	56·55	..	..	56·55	..	..	56·55	24·34
10	..	..	..	..	..	..	..	..	..	..	..	..	..	..
11	..	..	..	..	..	..	..	..	..	..	..	..	..	..
12	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Total Force applied in Tons	262·95	260·12	308·18	203·57	257·29	426·94	475·00	305·36	316·67	472·18	152·68	311·01	312·66	18·76
Total Number of Flexions before fracture	5	5	6	4	5	8	9	6	6	9	3	6	6	..

SET VI.

TABLE VII.—Increased Rigidity of Railway Axles under Flexion Strain.

Temperature of Axles during Experiment, 842° Fahrenheit = 450° Centigrade.
Deflection between Bearings at each bending, 2 inches.

Number of Bendings.	Force in Tons required at each Pressure to produce Flexion of Axles.												Average of 12 Experiments.	Total Increase of Rigidity per cent.
	Axle No. 61.	Axle No. 62.	Axle No. 63.	Axle No. 64.	Axle No. 65.	Axle No. 66.	Axle No. 67.	Axle No. 68.	Axle No. 69.	Axle No. 70.	Axle No. 71.	Axle No. 72.		
1	45·24	45·24	45·24	45·24	45·24	45·24	45·24	45·24	45·24	45·24	45·24	45·24	45·24	..
2	48·07	45·24	48·07	48·07	48·07	48·07	48·07	48·07	48·07	48·07	48·07	48·07	47·83	5·73
3	50·89	50·89	50·89	53·72	53·72	50·89	50·89	50·89	50·89	50·89	50·89	50·89	51·36	13·53
4	50·89	50·89	53·72	53·72	53·72	50·89	50·89	50·89	50·89	50·89	50·89	50·89	51·60	14·06
5	56·55	56·55	56·55	56·55	56·55	56·55	56·55	56·55	53·72	56·55	56·55	53·72	56·08	23·96
6	53·72	50·89	53·72	53·72	..	50·89	50·89	50·89	50·89	53·72	50·89	50·89	51·92	14·77
7	56·55	..	59·38	..	..	56·55	56·55	56·55	56·55	56·55	56·55	56·55	56·86	25·69
8	53·72	..	53·72	..	..	53·72	50·89	50·89	50·89	50·89	50·89	50·89	51·83	14·57
9	56·55	..	59·38	..	..	56·55	56·55	56·55	59·38	56·55	56·55	..	57·26	26·57
10	..	..	56·55	..	..	50·89	53·72	53·72	53·72	50·89	50·89	..	52·91	16·95
11	..	..	..	..	..	56·55	59·38	56·55	59·38	..	59·38	..	58·25	28·76
12	..	..	..	..	..	53·72 *	50·89 *	50·89 *	..	..	50·89 *	..	51·60	14·06
Total Force applied in Tons	472·18	299·70	537·22	311·02	257·30	851·07	689·91	740·80	579·62	520·24	797·35	407·16	538·63	18·06
Total number of Flexions	9	6	10	6	5	16	13	14	11	10	15	8	10	..

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* The bending of the axle was continued until it broke at the number of flexions stated, and having endured the Force in Tons given in the totals at the foot of each record in the above Table.

SET VII.

TABLE VIII.—INCREASED RIGIDITY OF RAILWAY AXLES UNDER FLEXION STRAIN.

Temperature of Axles during Experiment, 1112° Fahrenheit = 600° Centigrade.

Deflection between Bearings at each bending, 2 inches.

Number of Bendings.	Force in Tons required at each Pressure to produce Flexion of Axles.												Average of 12 Experiments.	Total Average Increase of Rigidity per cent.
	Axle No. 73.	Axle No. 74.	Axle No. 75.	Axle No. 76.	Axle No. 77.	Axle No. 78.	Axle No. 79.	Axle No. 80.	Axle No. 81.	Axle No. 82.	Axle No. 83.	Axle No. 84.		
1	2·83	2·83	2·83	2·83	2·83	2·83	2·83	2·83	2·83	2·83	2·83	2·83	2·83	..
2	2·83	5·65	2·83	2·83	2·83	2·83	2·83	2·83	2·83	2·83	2·83	2·83	3·06	8·13
3	5·65	5·65	5·65	5.65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	99·65
4	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	99·65
5	5·65	8·48	8·48	8·48	8·48	8·48	8·48	8·48	8·48	5·65	8·48	8·48	8·01	183·04
6	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	99·65
7	5·65	8·48	8·48	8·48	11·31	8·48	8·48	8·48	8·48	8·48	8·48	8·48	8·48	199·65
8	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	99·65
9	2·83	5·65	8·48	8·48	8·48	8·48	8·48	8·48	5·65	8·48	8·48	8·48	7·54	166·43
10	..	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	99·65
11	..	8·48	5·65	11·31	8·48	8·48	8·48	8·48	8·48	8·48	8·48	8·48	8·48	199·65
12	..	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	5·65	99·65
		*	*	*	*	*	*	*		*	*	*		
Total Force applied in Tons	42·39	144·20	90·48	118·75	180·95	155·51	214·88	138·54	76·65	209·23	155·51	206·40	143·96	123·16
Total number of Flexions	9	22	18	22	28	24	34	24	12	33	25	31	23·5	..

* The bending of the axle was continued until it broke at the number of flexions stated, and having endured the Force in Tons given in the totals at the foot of each record in the above Table.

SET VIII.

TABLE IX.—Effect of Slow and Repeated Flexion Strain on the Rigidity and Physical Properties of Railway Axles at Temperature of 50° F. or 10° C.

Index Number.	Description of Axles.	Number of Flexions.	Tensile Strength, Unstrained Portion, from Boss of Axle.				Tensile Strength, Strained Portion, from Middle of Axle.				Increased Rigidity per cent.	Reduced Elongation per cent.
			Original Diameter of Test-piece in Inches.	Breaking Stress. Tons per square inch.	Elongation per cent.	Reduction of Area per cent.	Original Diameter of Test-piece in Inches.	Breaking Stress. Tons per square inch.	Elongation per cent.	Reduction of Area per cent.		
P 3†	Wrought iron	1	·798	19·76	11·3	18·6	·798	23·32	21·3	33·6	18·02	..
P. 4*	”	1	·798	23·62	9·7	20·8	·798	23·92	15·0	29·4	1·27	..
P. 7*	”	8	·798	21·64	27·3	37·6	·798	24·18	13·0	25·2	11·74	7·69
P. 8†	”	8	·500	23·98	12·0	35·7	·500	26·17	9·0	29·1	9·13	25·00
P. 9†	”	12	·798	21·38	26·0	31·6	·798	28·56	13·0	23·0	33·58	50·00
P. 10*	”	12	·798	20·84	26·3	33·6	·797	26·47	7·3	16·0	27·02	72·24
C†	Bessemer steel	8	·798	37·86	26·7	47·2	·798	40·44	24·7	37·6	6·81	7·49
B	Siemens steel	8	·798	43·70	20·0	31·6	·798	43·80	16·3	39·6	0·23	18·50
W*	”	8	·798	24·60	27·0	33·6	·798	29·20	19·3	49·0	18·70	28·52

* The strain was in extension. † The strain was in compression.

N.B.—It was generally found that the appearance of the fractured test-pieces of the unstrained portions of the wrought iron axles were fibrous, whereas the fractured test-pieces of the strained portions showed generally from 40 to 60 per cent. of crystalline structure. This indicates that the previous straining of the axle by flexion had rendered the metal much more crystalline in structure.

The fractures of the test-pieces of the strained portions of the steel axles showed a much finer grain and smaller crystals than the fractures of the unstrained portions.

SET IX.

TABLE X.—EFFECT OF TORSIONAL STRAIN ON THE RIGIDITY AND PHYSICAL PROPERTIES OF RAILWAY AXLES AT NORMAL TEMPERATURE, 50° F. OR 10° C.

Index Number.	Description of Axles.	Normal Tensile Strength, Unstrained Portion of Axle.				Tensile Strength of Strained Portion after Torsional Stress.					Increased Rigidity per cent.	Reduced Elongation per cent.
		Original Diameter of Test-piece in Inches.	Breaking Stress. Tons per square inch.	Elongation per cent.	Reduction of Area per cent.	Angle of Torsion in Degrees.	Original Diameter of Test-piece in Inches.	Breaking Stress. Tons per square inch.	Elongation per cent.	Reduction of Area per cent.		
W	Wrought iron	1·000	21·38	29·7	37·6	11·25	0·797	21·02	31·0	39·5	..	..
W	„	0·752	23·13	28·0	28·5	22·50	0·750	24·55	22·0	33·9	5·92	21·43
W	„	0·748	23·08	29·0	40·0	45·00	0·752	24·89	18·7	27·5	7·84	35·52
W	„	1·000	21·68	26·0	37·6	45·00	0·748	22·07	22·7	35·5	1·80	12·69
W	„	0·798	22·76	28·0	37·6	90·00	0·798	24·50	17·7	33·6	5·67	36·79
W	„	0·750	22·83	30·3	42·3	180·00	0·756	30·02	5·0	21·4	31·49	83·50
W	„	0·788	22·40	26·0	36·1	180·00	0·796	29·28	11·3	29·1	30·74	56·54
W	„	0·788	22·40	26·0	36·1	270·00	0·798	30·80	6·3	14·0	37·50	75·77
W	„	0·798	21·24	28·7	35·6	360·00	0·564	30·72	6·0	8·4	44·63	79·09
B	Siemens steel	0·798	43·70	20·0	31·6	90·00	0·798	44·92	5·7	6·8	2·79	71·50
B	„	0·798	43·70	20·0	31·6	180·00	0·798	46·08	15·0	37·6	5·45	25·00
B	„	0·798	43·70	20·0	31·6	270·00	0·798	48·12	11·7	27·4	10·11	41·50
B	„	0·798	43·70	20·0	31·6	360·00	0·500	50·56	15·0*	26·0	15·69	25·00
W	„	0·798	24·60	27·0	33·6	90·00	0·798	26·74	22·74	37·6	8·70	15·93
W	„	0·798	24·60	27·0	33·6	180·00	0·798	30·00	21·30	55·8	21·95	21·11
W	„	0·798	24·60	27·0	33·6	270·00	0·798	31·88	6·30	14·0	29·59	76·67
C	Bessemer steel	0·798	37·86	26·7	47·2	90·00	0·798	40·90	18·3	31·6	8·03	31·46
C	„	0·798	37·86	26·7	47·2	180·00	0·798	42·18	13·3	23·0	11·41	50·19
C	„	0·798	37·86	26·7	47·2	270·00	0·798	44·10	12·3	23·0	16·48	53·93
C	„	0·798	37·86	26·7	47·2	360·00	0·798	44·28	1·7	2·0	16·96	93·63

The gauge points were 3 inches apart in all the above tests. The angle of torsion was taken in a length of 4 inches, see Fig. 3. The fractured test-piece (after tensile testing) of the wrought-iron axles in their normal condition showed a fibrous fracture. After a torsional strain of 180° the fractured test-piece showed 50 per cent. crystalline and 50 per cent. fibrous, whereas the fractured test-piece of the axles, which had been submitted to a torsional stress of 270°, was crystalline, with a trace fibrous.

The fractured test-piece (after tensile testing) of the Bessemer steel axle, which had been submiited to a torsional strain of 90°, showed 15 per cent. fibrous, 85 per cent. finely crystalline. After a torsional strain of 180° the fractured test-piece showed 10 per cent. fibrous, and 90 per cent. finely crystalline. The fractured test-piece of the axle, which had endured a torsional stress of 360°, was finely crystalline throughout. These results indicate that the torsional stress had apparently rendered the axle more crystalline, the crystallisation increasing with the increase of torsional stress.

* This elongation was taken between datum points 1 inch apart; the elongation on all the other tests of this Table were taken with datum points 3 inches apart.

SET X.

TABLE XI.—EFFECT OF TENSILE STRAIN ON THE RIGIDITY AND PHYSICAL PROPERTIES OF RAILWAY AXLES AT NORMAL TEMPERATURE.

Wrought-iron Axles.

Index Number.	Tensile Stress of Unstrained Axle.				Physical Properties of Axles after subjection to Tensile Strain as described below.				Increased Rigidity per cent.	Reduced Elongation per cent.
	Original Diameter of Test-piece in inches.	Breaking Stress. Tons per square inch.	Elongation per cent.	Reduction of Area per cent.	Original Diameter of Test-piece in inches.	Breaking Stress. Tons per square inch.	Elongation per cent.	Reduction of Area per cent.		
A	1·000	21·84	25·0	37·6	·798	22·42	16·0	25·2	2·66	36·0
B	·798	21·96	22·7	31·6	·798	21·96	23·0	31·6	..	..
C	1·128	21·87	25·3	..	1·128	25·85	20·0	24·6	18·20	20·95

Axle A.—A test-piece of 1 inch diameter was cut from this axle and placed in the tensile testing machine, the gauge points 3 inches apart. A stress gradually increasing from 5 to 12 tons was applied, which produced no extension. A weight of 12½ tons gave an extension of 0·01 inch between gauge points. Thirteen tons gave an extension of 0·02 inch, 14 tons showed an extension of 0·04 inch, 15 tons yielded an extension of 0·06 inch. The metal was thus extended by tensile stress of 15 tons to 2·0 per cent. of its length. Forty-eight hours from the time of stretching was allowed to elapse before making the tensile test of this strained piece from axle A. The piece was then turned down from 1 inch to ¾ inch diameter, and then tested to destruction, with results as given in the above Table.

Axle B.—A test piece ·798 diameter was cut from this axle and placed in the tensile testing machine, gauge points 3 inches apart. A stress of 7 tons was then gradually applied to the test-piece, producing an extension of 0·06 inch between gauge points. The test-piece was then taken out of the machine and allowed to remain at rest for about 24 hours. A weight of 8 tons was afterwards applied, producing an extension of 0·06 inch; the test-piece was then released from the load for 15 minutes. A stress of 9 tons was then applied, which showed an extension of 0·14 inch. The weight was taken off, and after an interval of 15 minutes a stress of 10 tons was applied, which showed an extension of 0·26 inch. The piece was then tested to destruction, with results as given in the above Table.

Axle C.—A piece was cut from this axle, 1½ inch diameter, with datum points 2 inches apart; the piece was then subjected to a stress of 31¼ tons and left for 11 days. It was then turned down to 1⅛ inch diameter and tested to destruction in the tensile machine, with the results given in the above Table.

SET XI.

TABLE XII.—Tensile Tests of Railway Axles.

20 Wrought-iron Axles.

Index Number of each Axle.	Diam. of Test-piece in Inches.	Distance between Test Points.	Breaking Strain per square inch in Tons.	Elongation per cent.	Reduction of Area per cent.
569	·798	3 inches	22·10	21·3	20·8
572	·798	„	22·74	32·0	33·6
591	·798	„	21·56	30·0	39·6
612	..	..	..	..	..
608	·798	3 inches	21·02	30·0	39·6
616	·798	„	20·74	28·7	39·6
600	·796	„	22·17	18·0	31·3
624	·797	„	20·76	30·3	41·5
635	·798	„	20·62	19·0	27·4
633	·798	„	22·24	25·7	35·6
644	·798	„	21·50	22·0	31·6
645	·798	„	21·08	26·0	29·4
646	·798	„	21·76	25·7	33·6
647	·798	„	20·98	22·0	27·4
662	·798	„	21·64	24·3	29·4
682	·798	„	21·62	23·7	27·4
687	·798	„	20·52	25·3	29·4
699	·798	„	22·00	23·7	25·2
702	·798	„	21·14	30·7	37·6
706	·798	„	21·42	27·3	37·6
Average	..	..	21·45	26·0	32·5

SET XI.—continued.

TABLE XIII.—TENSILE TESTS OF RAILWAY AXLES.

50 Siemens Steel Axles.

Index Number of each Axle.	Diameter of Test-piece in Inches.	Distance between Test Points.	Breaking Strain per square inch in Tons.	Elongation per cent.	Reduction of Area per cent.
1	·563	2 inches	32·01	31·0	46·9
2	·563	,,	31·73	29·5	41·8
3	·564	,,	33·12	30·0	44·4
4	·559	,,	33·18	30·0	46·1
5	·561	,,	32·19	35·0	58·7
6	·562	,,	32·58	33·0	52·0
7	..	3 inches	35·50	32·6	..
8	..	,,	35·50	28·0	..
9	..	,,	35·00	30·0	..
10	..	,,	38·00	31·3	..
11	..	,,	36·00	28·0	..
12	..	,,	36·00	27·6	..
13	..	,,	36·00	26·0	..
14	..	,,	36·50	27·3	..
15	..	,,	38·00	28·0	..
16	..	,,	36·00	26·6	..
17	..	,,	37·00	28·3	..
18	..	,,	38·00	27·0	..
19	·798	,,	35·50	30·0	48·0
20	·798	,,	35·25	30·0	53·4
21	·798	,,	36·40	26·0	41·6
22	·798	,,	37·10	25·0	39·8
23	·798	,,	38·30	26·0	42·6
24	·798	,,	36·00	27·0	43·4
25	·798	,,	35·53	28·0	49·0
26	·798	,,	35·71	27·0	49·0
27	·798	,,	38·60	26·0	37·6
28	·798	,,	35·00	27·6	49·2
29	·798	,,	35·26	29·1	49·0
30	·798	,,	32·00	31·0	50·8
31	·798	,,	37·70	26·6	45·4
32	·798	,,	32·00	32·0	52·4
33	·798	,,	32·00	29·0	50·8
34	·798	,,	34·90	28·0	47·2
35	·798	,,	32·00	28·3	49·0
36	·798	,,	36·80	26·3	41·6
37	·798	,,	32·00	32·0	50·0
38	·798	,,	31·46	30·0	52·4
39	·564	2 inches	28·40	36·0	61·6
40	·564	,,	29·48	35·5	59·2
41	·564	,,	32·76	32·5	54·8
42	·564	,,	29·64	34·5	59·2
43	·560	,,	30·85	35·0	58·5
44	·564	,,	29·36	36·0	61·6
45	·561	,,	32·27	32·0	54·3
46	·561	,,	32·43	34·0	49·0
47	·560	,,	30·85	36·0	58·5
48	·560	,,	34·76	32·5	58·5
49	·560	,,	29·39	34·5	61·0
50	·561	,,	29·84	34·0	56·3
Average	..	..	34·04	30·1	50·7

SET XI.—continued.

TABLE XIV.—Tensile Tests of Railway Axles.

50 Bessemer Steel Axles.

Index Number of each Axle.	Diam. of Test-piece in Inches.	Distance between Test Points.	Breaking Strain per square inch in Tons.	Elongation per cent.	Reduction of Area per cent.
1	·561	2 inches	31·26	33·0	58·7
2	·561	,,	32·35	34·5	58·7
3	·561	,,	31·64	33·5	58·7
4	·561	,,	30·20	36·0	56·3
5	·561	,,	32·55	31·5	58·7
6	·565	,,	27·76	24·5	42·0
7	·565	,,	34·70	29·5	42·0
8	·565	,,	31·88	31·0	56·8
9	·565	,,	32·24	34·0	56·8
10	·565	,,	33·76	29·0	52·4
11	·565	,,	29·72	33·5	59·2
12	·565	,,	28·04	32·0	56·8
13	·562	,,	30·08	31·0	58·9
14	·562	,,	31·13	34·5	61·3
15	·564	,,	30·36	33·5	59·2
16	·564	,,	28·76	34·5	59·2
17	·564	,,	30·00	34·0	59·2
18	·564	,,	26·16	36·5	63·6
19	..	3 inches	37·00	25·0	..
20	..	,,	38·00	28·0	..
21	..	,,	38·70	26·0	..
22	..	,,	38·00	30·0	..
23	..	,,	35·80	28·0	..
24	..	,,	36·00	29·0	..
25	..	,,	40·00	26·0	..
26	..	,,	38·00	25·3	..
27	..	,,	37·00	27·3	..
28	..	,,	36·00	27·0	..
29	..	,,	36·00	26·6	..
30	..	,,	36·60	29·0	..
31	·798	,,	35·84	27·3	48·98
32	·798	,,	38·20	26·0	47·16
33	·798	,,	35·25	28·0	45·60
34	·798	,,	35·80	30·0	50·4
35	·798	,,	35·75	29·3	47·2
36	·798	,,	35·60	28·0	60·8
37	·798	,,	35·00	32·0	54·0
38	·798	,,	35·00	27·0	48·0
39	·798	,,	36·00	28·6	52·2
40	·798	,,	35·50	27·3	59·8
41	·798	,,	34·75	28·6	48·4
42	·798	,,	35·00	28·0	45·0
43	·798	,,	35·20	25·3	37·0
44	·798	,,	35·20	32·6	55·2
45	·798	,,	35·00	31·3	53·4
46	·788	,,	35·00	32·6	49·0
47	·798	,,	34·75	30·0	48·0
48	·798	,,	34·90	29·3	49·6
49	.798	,,	35·50	30·0	48·4
50	·798	,,	35·00	28·7	46·8
Average	..	..	34·16	29·9	53·0

SET XII.

TABLE XV.—Effect of Impact Strain on the Rigidity of Railway Axles at Warm Temperatures.

12 Wrought-Iron Axles.

Index Number of each Axle.	Diameter of Middle in Inches.	Temperature of Axles. Fahrenheit.	Energy of each Impact in Foot-tons.	Permanent Deflection between Bearings (3 feet 6 inches apart) in Inches.					Total Increase of Rigidity per cent.
				1st Impact.	2nd Impact.	3rd Impact.	4th Impact.	5th Impact.	
4	$4\frac{1}{2}$	212	10	$3\frac{3}{4}$	$2\frac{7}{8}$	$2\frac{1}{8}$	$2\frac{1}{4}$	2	46·67
5	,,	,,	10	$3\frac{7}{8}$	3	$2\frac{3}{8}$	$2\frac{1}{8}$	$2\frac{7}{8}$	25·80
7	,,	,,	10	$3\frac{3}{4}$	3	$2\frac{3}{8}$	$2\frac{3}{8}$	2	46·67
Average..	..	..	..	..	..	..	..	..	39·71
124	$4\frac{1}{2}$	100	5	$1\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{3}{16}$	$1\frac{9}{16}$	$1\frac{1}{2}$	7·69
125	,,	,,	5	$1\frac{3}{4}$	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{5}{16}$	25·00
129	,,	,,	5	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{11}{16}$	$1\frac{9}{16}$	$1\frac{9}{16}$	3·85
130	,,	,,	5	$1\frac{5}{8}$	$1\frac{11}{16}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{1}{2}$	7·69
131	,,	,,	5	$1\frac{5}{8}$	$1\frac{13}{16}$	$1\frac{11}{16}$	$1\frac{11}{16}$	$1\frac{9}{16}$	3·85
132	,,	,,	5	$1\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{9}{16}$	10·71
133	,,	,,	5	$1\frac{11}{16}$	$1\frac{3}{4}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{7}{16}$	14·81
135	,,	,,	5	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{9}{16}$	$1\frac{7}{16}$	11·54
136	,,	,,	5	$1\frac{11}{16}$	$1\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{9}{16}$	$1\frac{1}{2}$	11·11
Average..	..	..	..	..	..	..	..	..	10·69

SET XII.—continued.

TABLE XVI.—Effect of Impact Strain on the Rigidity of Railway Axles at Normal Temperature. 50 Wortley Wrought-iron Axles.

Index Number of each Axle.	Diameter of Middle in Inches.	Temperature of Axles. Fahrenheit.	Energy of each Impact in Foot-tons.	Permanent Deflection between Bearings (3 feet 6 inches apart) in Inches.					Total Increase of Rigidity per cent.
				1st Impact.	2nd Impact.	3rd Impact.	4th Impact.	5th Impact.	
569	4½	about 50°	17·86	4¼	straight	4	straight	4	5·88
570	"	"	"	4¼	"	"	"	"	5·88
571	"	"	"	4¼	"	"	"	"	5·88
572	"	"	"	4¼	"	"	"	"	5·88
575	"	"	"	4¼	"	"	"	"	5·88
576	"	"	"	4¼	"	"	"	"	5·88
577	"	"	"	4¼	"	"	"	"	5·88
578	"	"	"	4¼	"	"	"	"	5·88
580	"	"	"	4¼	"	"	"	"	5·88
581	"	"	"	4¼	"	"	"	"	5·88
582	"	"	"	4¼	"	"	"	"	5·88
583	"	"	"	4¼	"	"	"	"	5·88
584	"	"	"	4¼	"	"	"	"	5·88
585	"	"	"	4¼	"	"	"	"	5·88
586	"	"	"	4⅛	"	"	"	"	3·03
587	"	"	"	4¼	"	"	"	"	5·88
591	"	"	"	4¼	"	"	"	"	5·88
593	"	"	"	4¼	"	"	"	"	5·88
594	"	"	"	4¼	"	"	"	"	5·88
595	"	"	"	4¼	"	"	"	"	5·88
596	"	"	"	4⅛	"	"	"	"	3·03
600	"	"	"	4¼	"	"	"	"	5·88
608	"	"	"	4¼	"	"	"	"	5·88
612	"	"	"	4⅛	"	"	"	"	3·03
616	"	"	"	4¼	"	"	"	"	5·88
624	"	"	"	4¼	"	"	"	"	5·88
626	"	"	"	4⅛	"	"	"	"	3·03
633	"	"	"	4¼	"	"	"	"	5·88
635	"	"	"	4¼	"	"	"	"	5·88
644	"	"	"	4¼	"	"	"	"	5·88
645	"	"	"	4¼	"	"	"	"	5·88
646	"	"	"	4¼	"	"	"	"	5·88
647	"	"	"	4¼	"	"	"	"	5·88
662	"	"	"	4¼	"	"	"	"	5·88
682	"	"	"	4¼	"	"	"	"	5·88
687	"	"	"	4¼	"	"	"	"	5·88
699	"	"	"	4¼	"	"	"	"	5·88
702	"	"	"	4¼	"	"	"	"	5·88
703	"	"	"	4¼	"	"	"	"	5·88
704	"	"	"	4¼	"	"	"	"	5·88
709	"	"	"	4¼	"	"	"	"	5·88
710	"	"	"	4¼	"	"	"	"	5·88
711	"	"	"	4¼	"	"	"	"	5·88
712	"	"	"	4¼	"	"	"	"	5·88
713	"	"	"	4¼	"	"	"	"	5·88
715	"	"	"	4¼	"	"	"	"	5·88
706	"	"	"	4¼	"	"	"	"	5·88
733	"	"	"	4¼	"	"	"	"	5·88
738	"	"	"	4¼	"	"	"	"	5·88
785	"	"	"	4⅛	"	"	"	"	3·03
Average ..	..	..	..	..	..	..	..	..	5·60

A further series of experiments, made on 33 Wortley wrought-iron railway axles, gave even better results, as regards increase of rigidity, than those on Table XVI., the total average increase of rigidity at the end of the fifth blow in this further series of experiments being only 2·27 per cent. for wrought-iron, and 10·27 increase per cent. of rigidity for Bessemer-steel, and 9·64 per cent. increase of rigidity for Siemens-steel axles.

SET XII.—continued.

TABLE XVI. (*continued*).—EFFECT OF IMPACT STRAIN ON THE RIGIDITY OF RAILWAY AXLES AT NORMAL TEMPERATURE. 33 Wortley Wrought-Iron Axles.

Index Number of each Axle.	Diameter of Middle in Inches.	Temperature of Axles. Fahrenheit.	Energy of each Impact in Foot-tons.	Permanent Deflection between Bearings (3 feet 6 inches apart) in Inches.					Total Increase of Rigidity per cent.
				1st Impact.	2nd Impact.	3rd Impact.	4th Impact.	5th Impact.	
1196	4½	about 50°	17·86	4⅜	straight	4⅜	straight	4¼	2·86
1197	,,	,,	,,	4⅜	,,	4⅜	,,	4¼	2·86
1202	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1203	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1206	,,	,,	,,	4⅝	,,	4½	,,	4½	2·70
1208	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1209	,,	,,	,,	4⅜	,,	4⅜	,,	4¼	2·86
1210	,,	,,	,,	4½	,,	4½	,,	4½	..
1213	,,	,,	,,	4⅜	,,	4⅜	,,	4¼	2·86
1214	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1224	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1225	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1226	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1227	,,	,,	,,	4⅝	,,	4⅝	,,	4⅝	..
1229	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1230	,,	,,	,,	4⅝	,,	4⅝	,,	4½	2·70
1231	,,	,,	,,	4⅝	,,	4⅝	,,	4½	2·70
1232	,,	,,	,,	4⅝	,,	4⅝	,,	4½	2·70
1233	,,	,,	,,	4⅝	,,	4⅝	,,	4½	2·70
1236	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1237	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1238	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1240	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1242	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1244	,,	,,	,,	4⅜	,,	4⅜	,,	4⅜	..
1245	,,	,,	,,	4⅝	,,	4⅝	,,	4⅝	..
1246	,,	,,	,,	4⅝	,,	4⅝	,,	4⅝	..
1247	,,	,,	,,	4½	,,	4½	,,	4½	..
1250	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1251	,,	,,	,,	4⅝	,,	4⅝	,,	4½	2·70
1252	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1253	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
1254	,,	,,	,,	4½	,,	4½	,,	4⅜	2·78
Average	..	..	..	..	..	..	..	..	2·27

SET XII.—continued.

TABLE XVII.—Effect of Impact Strain on the Rigidity of Railway Axles at Normal Temperature. 50 Siemens Steel Axles.

Index No. of each Axle.	Diam. of Middle in Inches.	Temperature of Axles. Fahrenheit.	Energy of each Impact in Foot-tons.	Permanent Deflection between Bearings (3 feet 6 inches apart) in Inches. 1st Impact.	2nd Impact.	3rd Impact.	4th Impact.	5th Impact.	Total Increase of Rigidity per cent.
1	$4\frac{3}{4}$	about 50°	16	$2\frac{3}{4}$	straight	$2\frac{3}{4}$	straight	$2\frac{1}{2}$	9·09
2	”	”	16	$2\frac{5}{8}$	”	$2\frac{1}{2}$	”	$2\frac{3}{8}$	9·52
3	”	”	16	$2\frac{5}{8}$	”	$2\frac{1}{2}$	”	$2\frac{3}{8}$	9·52
4	”	”	16	$2\frac{9}{16}$	”	$2\frac{3}{8}$	”	$2\frac{1}{4}$	12·20
5	”	”	16	$2\frac{3}{4}$	”	$2\frac{1}{2}$	”	$2\frac{3}{8}$	13·64
6	”	”	16	$2\frac{3}{4}$	”	$2\frac{5}{8}$	”	$2\frac{5}{8}$	4·54
7	$4\frac{1}{2}$	”	17·86	$3\frac{1}{2}$	”	$3\frac{1}{4}$	”	3	14·29
8	”	”	17·86	$3\frac{1}{2}$	”	$3\frac{3}{8}$	”	$3\frac{1}{4}$	7·14
9	”	”	17·86	$3\frac{3}{8}$	”	$3\frac{1}{8}$	”	3	11·11
10	”	”	17·86	$3\frac{3}{8}$	”	3	”	$2\frac{3}{4}$	18·52
11	”	”	17·86	$3\frac{3}{8}$	”	$3\frac{1}{4}$	”	3	11·11
12	”	”	17·86	$4\frac{1}{4}$	”	4	”	$3\frac{3}{4}$	11·76
13	”	”	17·86	4	”	$3\frac{3}{4}$	”	$3\frac{1}{2}$	12·50
14	”	”	17·86	$4\frac{3}{4}$	”	$4\frac{1}{2}$	”	4	15·79
15	”	”	17·86	$4\frac{1}{2}$	”	$4\frac{1}{4}$	”	$4\frac{1}{8}$	8·33
16	”	”	17·86	$4\frac{1}{8}$	”	4	”	4	3·03
17	”	”	17·86	$4\frac{1}{4}$	”	$4\frac{1}{8}$	”	4	5·88
18	”	”	17·86	$3\frac{3}{4}$	”	$3\frac{1}{2}$	”	$3\frac{1}{4}$	13·33
19	”	”	18	$3\frac{1}{2}$	”	$3\frac{1}{4}$	”	$3\frac{1}{4}$	7·14
20	”	”	18	$3\frac{3}{8}$	”	$3\frac{1}{8}$	”	3	11·11
21	”	”	18	$3\frac{1}{2}$	”	$3\frac{3}{8}$	”	$3\frac{5}{16}$	5·36
22	”	”	18	$3\frac{3}{8}$	”	$3\frac{3}{8}$	”	$3\frac{1}{4}$	3·70
23	”	”	18	$3\frac{3}{4}$	”	$3\frac{1}{2}$	”	$3\frac{3}{8}$	10·00
24	”	”	18	$3\frac{7}{8}$	”	$3\frac{1}{2}$	”	$3\frac{1}{4}$	16·13
25	$4\frac{1}{4}$	”	18	$4\frac{1}{8}$	”	4	”	4	3·03
26	”	”	18	$4\frac{1}{8}$	”	4	”	4	3·03
27	”	”	18	$4\frac{1}{4}$	”	4	”	$3\frac{5}{8}$	14·71
28	”	”	18	$4\frac{3}{8}$	”	4	”	$3\frac{1}{2}$	20·00
29	”	”	18	$4\frac{1}{8}$	”	$3\frac{7}{8}$	”	$3\frac{3}{4}$	9·09
30	”	”	18	$4\frac{1}{2}$	”	$4\frac{1}{8}$	”	$3\frac{3}{4}$	16·67
31	”	”	18	$4\frac{1}{2}$	”	$4\frac{1}{4}$	”	$3\frac{7}{8}$	13·89
32	”	”	18	$4\frac{1}{8}$	”	$3\frac{3}{4}$	”	$3\frac{1}{2}$	15·15
33	”	”	18	$4\frac{1}{8}$	”	$3\frac{3}{4}$	”	$3\frac{1}{2}$	15·15
34	”	”	18	4	”	$3\frac{3}{4}$	”	$3\frac{5}{8}$	9·37
35	”	”	18	$4\frac{1}{4}$	”	4	”	$3\frac{3}{4}$	11·76
36	”	”	18	4	”	$3\frac{3}{4}$	”	$3\frac{5}{8}$	9·37
37	”	”	18	$4\frac{1}{8}$	”	$3\frac{3}{4}$	”	$3\frac{3}{8}$	18·18
38	”	”	18	$4\frac{1}{8}$	”	$3\frac{7}{8}$	”	$3\frac{5}{8}$	12·12
39	4	”	16	$5\frac{1}{4}$	”	$5\frac{1}{8}$	”	5	4·76
40	”	”	16	5	”	5	”	$4\frac{7}{8}$	2·50
41	$3\frac{3}{4}$	”	12	$4\frac{5}{8}$	”	$4\frac{3}{8}$	”	$4\frac{1}{4}$	8·11
42	”	”	12	$5\frac{1}{4}$	”	5	”	$4\frac{7}{8}$	7·14
43	”	”	12	$4\frac{1}{2}$	”	$4\frac{1}{8}$	”	$4\frac{1}{8}$	8·33
44	”	”	12	$4\frac{1}{2}$	”	$4\frac{3}{8}$	”	$4\frac{1}{8}$	8·33
45	”	”	12	$4\frac{3}{4}$	”	$4\frac{5}{8}$	”	$4\frac{5}{8}$	2·63
46	”	”	12	$4\frac{3}{4}$	”	$4\frac{11}{16}$	”	$4\frac{5}{8}$	2·63
47	”	”	12	5	”	$4\frac{7}{8}$	”	$4\frac{7}{8}$	2·50
48	”	”	12	$4\frac{7}{8}$	”	$4\frac{7}{8}$	”	$4\frac{3}{4}$	2·56
49	”	”	12	$5\frac{1}{4}$	”	5	”	$4\frac{7}{8}$	7·14
50	”	”	12	$5\frac{1}{2}$	”	5	”	5	9·09
Average	..	..	..	..	..	..	..	..	9·64

SET XII.—continued.

TABLE XVIII.—EFFECT OF IMPACT STRAIN ON THE RIGIDITY OF RAILWAY AXLES AT NORMAL TEMPERATURE. 50 Bessemer Steel Axles.

Index No. of each Axle.	Diam. of Middle in Inches.	Temperature of Axles. Fahrenheit.	Energy of each Impact in Foot-tons.	Permanent Deflection between Bearings (3 feet 6 inches apart) in Inches.					Total Increase of Rigidity per cent.
				1st Impact.	2nd Impact.	3rd Impact.	4th Impact.	5th Impact.	
1	$4\frac{3}{4}$	about 50°	16	$2\frac{11}{16}$	straight	$2\frac{3}{8}$	straight	$2\frac{1}{4}$	16·28
2	,,	,,	16	$2\frac{5}{8}$	,,	$2\frac{5}{16}$	,,	$2\frac{1}{8}$	19·05
3	,,	,,	16	$2\frac{13}{16}$	,,	$2\frac{1}{2}$	,,	$2\frac{3}{8}$	15·56
4	,,	,,	16	$2\frac{5}{8}$	,,	$2\frac{3}{8}$	,,	$2\frac{1}{4}$	14·29
5	,,	,,	16	$2\frac{1}{2}$	,,	$2\frac{1}{4}$	,,	$2\frac{1}{8}$	15·00
6	,,	,,	16	$2\frac{7}{8}$	,,	$2\frac{1}{2}$	,,	$2\frac{7}{16}$	15·22
7	,,	,,	16	$2\frac{5}{16}$	,,	2	,,	$1\frac{15}{16}$	16·22
8	,,	,,	16	$2\frac{3}{4}$	,,	$2\frac{1}{2}$	,,	$2\frac{7}{16}$	11·36
9	,,	,,	16	$2\frac{1}{2}$	,,	$2\frac{3}{16}$	,,	$2\frac{1}{16}$	17·50
10	,,	,,	16	$2\frac{7}{16}$	,,	$2\frac{1}{8}$	,,	2	17·95
11	,,	,,	16	$2\frac{3}{4}$	,,	$2\frac{1}{2}$	,,	$2\frac{3}{8}$	13·64
12	,,	,,	16	$2\frac{15}{16}$	,,	$2\frac{11}{16}$	,,	$2\frac{5}{8}$	10·64
13	,,	,,	16	$2\frac{5}{8}$	,,	$2\frac{1}{4}$	,,	$2\frac{1}{8}$	19·05
14	,,	,,	16	$2\frac{5}{8}$	,,	$2\frac{3}{8}$	,,	$2\frac{1}{4}$	14·29
15	,,	,,	16	$2\frac{11}{16}$	,,	$2\frac{7}{16}$	,,	$2\frac{5}{16}$	13·95
16	,,	,,	16	$2\frac{11}{16}$	,,	$2\frac{7}{16}$	,,	$2\frac{1}{4}$	16·28
17	,,	,,	16	$2\frac{13}{16}$	,,	$2\frac{9}{16}$	,,	$2\frac{9}{16}$	8·89
18	,,	,,	16	3	,,	$2\frac{7}{8}$	,,	$2\frac{7}{8}$	4·17
19	$4\frac{1}{2}$	,,	17·86	3	,,	$2\frac{3}{4}$	,,	$2\frac{3}{4}$	8·33
20	,,	,,	17·86	$3\frac{1}{4}$	,,	$3\frac{1}{4}$	,,	$3\frac{1}{4}$	..
21	,,	,,	17·86	$3\frac{1}{2}$	,,	$3\frac{1}{4}$	,,	$3\frac{1}{4}$	7·14
22	,,	,,	17·86	$3\frac{5}{8}$	,,	$3\frac{1}{2}$	,,	$3\frac{1}{4}$	10·34
23	,,	,,	17·86	$3\frac{1}{2}$	,,	$3\frac{3}{8}$	,,	$3\frac{1}{4}$	7·14
24	,,	,,	17·86	$4\frac{1}{8}$	,,	$3\frac{3}{4}$	,,	$3\frac{5}{8}$	12·12
25	,,	,,	17·86	$3\frac{1}{4}$	,,	$3\frac{1}{8}$	,,	$3\frac{1}{8}$	3·85
26	,,	,,	17·86	4	,,	$3\frac{3}{4}$	,,	$3\frac{1}{2}$	12·50
27	,,	,,	17·86	$2\frac{3}{4}$	,,	$2\frac{1}{2}$	,,	$2\frac{1}{4}$	18·18
28	,,	,,	17·86	$3\frac{3}{8}$	,,	$3\frac{1}{8}$	,,	3	11·11
29	,,	,,	17·86	$3\frac{1}{4}$	,,	3	,,	3	7·69
30	,,	,,	17·86	$3\frac{3}{4}$	,,	$3\frac{1}{2}$	,,	$3\frac{1}{4}$	13·33
31	,,	,,	18	$3\frac{1}{8}$	,,	3	,,	$2\frac{3}{4}$	12·00
32	,,	,,	18	3	,,	$2\frac{3}{4}$	,,	$2\frac{5}{8}$	12·50
33	,,	,,	18	$3\frac{1}{2}$	,,	$3\frac{3}{8}$	,,	$3\frac{1}{4}$	7·14
34	,,	,,	18	$3\frac{1}{2}$	,,	$3\frac{1}{4}$	,,	$3\frac{1}{4}$	7·14
35	,,	,,	18	$3\frac{3}{8}$	,,	$3\frac{1}{8}$	,,	$3\frac{1}{8}$	7·41
36	,,	,,	18	$3\frac{3}{8}$	,,	$3\frac{1}{4}$	,,	$3\frac{1}{4}$	3·70
37	,,	,,	18	$3\frac{1}{2}$	,,	$3\frac{3}{8}$	,,	$3\frac{3}{8}$	3·57
38	,,	,,	18	$3\frac{1}{2}$	,,	3	,,	$2\frac{7}{8}$	17·86
39	,,	,,	18	$3\frac{1}{2}$	,,	$3\frac{3}{8}$	,,	$3\frac{1}{4}$	7·14
40	,,	,,	18	$3\frac{3}{8}$	,,	$3\frac{1}{4}$	,,	$3\frac{1}{4}$	3·70
41	,,	,,	18	$3\frac{1}{2}$	,,	$3\frac{3}{8}$	,,	$3\frac{5}{16}$	5·36
42	,,	,,	18	$3\frac{5}{8}$	,,	$3\frac{1}{2}$	,,	$3\frac{1}{2}$	3·45
43	,,	,,	18	$3\frac{5}{8}$	,,	$3\frac{1}{2}$	,,	$3\frac{1}{2}$	3·45
44	,,	,,	18	$3\frac{1}{2}$	,,	$3\frac{3}{8}$	,,	$3\frac{3}{8}$	3·57
45	,,	,,	18	$3\frac{9}{16}$	,,	$3\frac{1}{2}$	,,	$3\frac{1}{2}$	1·75
46	,,	,,	18	$3\frac{3}{8}$	,,	$3\frac{1}{4}$	,,	$3\frac{1}{4}$	3·70
47	,,	,,	18	$3\frac{1}{2}$	,,	$3\frac{3}{8}$	,,	$3\frac{1}{4}$	7·14
48	,,	,,	18	$3\frac{5}{8}$	,,	$3\frac{3}{8}$	,,	$3\frac{1}{4}$	10·34
49	,,	,,	18	$3\frac{1}{4}$	,,	3	,,	3	7·69
50	,,	,,	18	$3\frac{1}{2}$	,,	$3\frac{3}{8}$	,,	$3\frac{3}{8}$	3·57
Average	..	..	..	..	..	..	..	..	10·27

Mr. Thomas Nash, M.Inst.M.E., and one or two other friends, have kindly assisted the author in connection with the tests of some of the axles included in Set XII, some of the steel ones having been examined in Belgium.

DISCUSSION.

The PRESIDENT, in moving a vote of thanks to the author, said he was sure that all present would agree with him that the paper was a highly interesting and valuable one, in the production of which Mr. Andrews must have spent a great deal of time and have spared neither trouble nor expense.

The vote of thanks was carried by acclamation.

Mr. W. WORBY BEAUMONT said that the experimental results which had been set forth in the paper rendered it necessary for a master mind to do for the readers a certain amount of interpretation and translation. Something more was wanted to enable them to say what material would be best for any given purpose. The present experiments, and others which had been made by different experimenters, showed that the treatment of the same material brought about, not only very different results as far as the crystalline structure was concerned, but also very different mechanical properties. They also showed that the same material worked and tested under different conditions would give very different results. The diagrams indicated how various the forms of the crystals were in different sections, and yet how generally all the crystals took larger dimensions and more similar forms as they were found on the exterior of the section. Again, it was noticeable that the effect of rolling under different conditions was to mask the character of the crystals altogether, and, in fact, to make one wonder whether they were the crystals themselves, or an aggregate of crystals mechanically broken up in the cold rolling process, rather than crystals caused to take different forms and sizes. Then the sections said to show a large area, occupied in some cases by carbide of iron, suggested some very puzzling relations as to constitution and strength. With respect to the cold rolled section, the crystals were found taking very different shapes, although the difference between the amount and character of the mechanical work done upon them could not have brought about the changes in the form of the crystals, a fact which made one wonder whether the microscope had, after all, seen all that there was in a section, and whether the lantern views exhibited would show anything which would help them to understand some of the peculiarities and contradictions which were often found in connection with the fracture both of wrought iron and of steel. The section of the cold-rolled axle gave crystals extending in parallel lines nearly across a great diameter, and so entirely of a different form, and apparently taking up the whole diameter so completely, that it seemed a question whether in that case the microscope had been able to differentiate between the crystals at all.

With regard to some of the steel axles which had been shown, he had recently noticed that some experiments had been made by American investigators on certain materials used under different conditions, as, for instance, connecting rods in which there was a reciprocating stress alternating between compression and tension, and in which at the same time there was an alternating transverse stress due to the inertia of the connecting rod itself as it went up and down, and a similar material used as a shaft; and it was found that while, on the one hand, the material having the greatest quantity of carbon gave the poorest results with slowly applied stresses, the connecting rods, the material which had the greatest quantity of carbon, withstood the greatest stresses and the greatest number of changes of the application of the force involved. In considering any of these tests of materials, it was necessary to examine carefully the difference between the nature of the stress as regarded rapidity of application, as well as intensity of application, and, in fact, to connect together the rate at which the material had to receive and transmit a given stress, and the rate at which the material could transmit that stress through itself without approach to the limit of elastic extension. They had, in fact, to remember the great difference that there was in a material which would best meet conditions in which the flexibility would be the chief desideratum, or in which elasticity would be the chief desideratum. He (Mr. Beaumont) must confess that to be able to derive anything from the paper he felt that it was necessary to go very carefully into the masses of figures, and place himself in the position of the experimenter, before he got hold of the lesson which might perhaps be learned from them as an engineer wishing to specify the best material for a given purpose.

Mr. R. Lander McLaren said that railway men in general owed a debt of gratitude to Mr. Andrews for the results which he had brought before them, and especially for showing that apparently iron, such as he manufactured, had enormous advantages over steel, whether made by the Bessemer process or the Siemens process, for shafts and axles. The experience of many years had undoubtedly proved that the best form for an axle was a tapering one, such as was shown in the diagram. The effect of that form was to impart a sort of whipping or ringing action to the axle, and to allow the main effect of the torsion to take place at the centre of the axle. He believed that that form of axle would continue. He did not know whether any of the experiments had been made upon axles of a different form.

Mr. ANDREWS said that the whole of the axles were of precisely the same form, size and construction as the one shown in the diagram.

Mr. McLAREN (resuming) said that, with regard to the use of the figures, until they knew definitely the value of the horizontal and vertical forces—that was to say, the maximum value of those forces, acting on a railway axle—he did not see how, in designing an axle upon any scientific principles, they were to make use of the author's figures with regard to the relative rigidity of the different metals. He wished to know whether the author considered that the results of those tests applied also to steel tyres. The tendency now-a-days was to use as hard a metal as a tool would face, and to thicken up the tyres in their dimensions generally. Of course the life of an axle might be looked at in two main ways; first, with regard to the axle proper, and secondly, with regard to the wear of the journals. An axle might be thrown out of use by journal wear when it was really quite sound and safe as an axle proper; that was, between the wheel bosses.

With regard to the use of wrought iron, he believed that the Americans had gone rather more fully into that subject than English engineers had. The opinion in America seemed to be that wrought-iron axles were responsible for more hot boxes than steel ones were. They attributed that to the fact that flaws and seams were more likely to occur and cause trouble in wrought-iron journals than in steel. With regard to the type of axle box, the Americans were far ahead of the English. They had gone in for standardising, and therefore he imagined that steel axles and iron axles had been tried under the same conditions. Rail and tyre wear, coupled with hot journals and broken axles, were points which demanded a great deal of attention. The Americans had, some years ago, tried various designs in the shape of independent wheel rotation, and various kinds of material; but the conditions now were rather different to what they were six or ten years ago. Capital had a very low rate of interest, while, on the other hand, labour and maintenance charges were going up by leaps and bounds, and heavy loads and high speeds were rapidly extending. Personally, he believed that independent wheel rotation was the right thing to adopt, perhaps, in connection with wrought iron axles, but wrought iron alone would not overcome the difficulty. As Mr. Andrews had rightly pointed out, torsion was the thing with which they had to contend in axles. Let them do away with torsion altogether, if possible, and adopt independent wheel rotation. The attempt had been made in many forms, but they had all failed. However, he believed that in the principle of independent wheel rotation lay the solution of the difficulty to a very large extent, as soon as a practical design could be found.

Then came next the question of journal wear, and the name was legion of boxes, oils, and dust shields, which had been tried in connection with that point. The Americans had proceeded on somewhat different lines from the English. They went in for a sort of rocking key or rocking brass, in order to distribute the weight more equally over the journal, and prevent its being concentrated upon any one point, as it would be towards the shoulder of the journal. The whole weight, and probably double or treble the ordinary static load, got thrown on to one or two square inches; and then occurred the difficulty of heating, and the journal approached the temperature of that shown on the diagram, and trouble resulted. Dust shields of various forms had been tried, but he only knew of one that was absolutely efficient. A rocking brass and dust shield seemed to him to be interdependent, one being of little use without the other. Engineers in this country used indiarubber cushions at the end of the springs, one of the points then gained being that the rocking action of the axle and the brass was largely taken up by the indiarubber through the medium of the springs and the boxes. The Americans on their freight cars used a rocking key with a radius of about 40 inches, and they employed coil springs. The unfortunate part was that the radius of the keys was not struck from the right point, namely, the centre of the journal, but from a point very much below, and therefore a cross strain still took place on the box. Consequently the coil springs got loaded out of the centre, and were a source of constant trouble.

As a side issue he took it that independent wheel rotation afforded a solution of the difficulty of radial axles. Ordinary radial axles were not a success. The radius of motion could not be so adjusted that it would be suitable for all curves. The result was that the pushing action which tended to force the axle round into the curves was a varying one, while the load was approximately constant. That accounted for the unsatisfactory state of the tyres which was observed in connection with radial axles. They had lately heard a great deal about the bogie system, and most English engineers seemed to be very uncertain on the point, and still stuck to the old four-wheeler. The result was that the Americans said that the English engineers did not get the full value of their railways, and did not handle their traffic properly. On the other hand, there were many points in favour of the four-wheeler, but still he thought that, if independent wheel rotation was adopted with six-wheeled wagons similar to those employed in the Caledonian Railway, but with the two end axles thus fitted into radial frames with check springs, and an ordinary rigid axle in the centre, the axle failures would be fewer, and a proper radial system attained, which would be more suitable for the goods traffic of this country, and not require constant attention.

He wished to ask Mr. Andrews, firstly, whether he thought that the same results would apply to tyres as to axles; secondly, whether he had ever gone into the question of the maximum, horizontal and vertical forces acting on an axle in going round curves and at speed, and, if so, how the point bore upon the figures which the paper contained; and, thirdly, whether the subject of independent wheel rotation in some shape or form could not, in conjunction with wrought-iron axles, be brought to bear on the subject, and therefore get over, or, at all events, minimise to a large extent, the tremendous risk which undoubtedly existed in connection with ordinary axles at the present moment.

Mr. J. Barker said that in the preparation of his paper the author had undertaken a herculean task. Having had a great deal to do with testing and investigating the causes of failure of axles, he was able to appreciate the work which the author had taken in hand. Some results had been very clearly brought out in the paper. One was that strains of all kinds increased the rigidity of the materials, and that it did so at all temperatures. Perhaps that was a fact which was not very generally known. Another important fact which had been brought out was the injurious effect of increased temperature on the materials at over 100° F., and especially between 500° and 600°, or the boiling point of oil. But it did not appear, as had been already pointed out, that there was any law deducible from the experiments. The tables seemed to show various anomalies which perhaps Mr. Andrews could explain. But, notwithstanding the apparent anomalies, a great step had been taken in connection with the present subject, and much had been achieved. Railway engineers, however, still wanted to know the effect of a large number of small strains, which only bent an axle slightly at every conceivable angle. He meant not only torsional strains, but, more particularly, those strains which were produced by the action of the rails on the flanges of the wheels, and which put a constant flexure upon the axle to a small extent. In other words, given a good axle, how many revolutions under a certain set of conditions could an axle sustain when strained within its elastic limit? Then they would also like to know how many revolutions a similar axle under similar conditions could sustain when strained to its maximum working strain. With such information before him, a locomotive engineer knowing the special features of his traffic and road, could form a fairly good estimate of how long he ought to allow his axles to run. Some years ago he was asked by the secretary of another society to suggest subjects for papers and investigation; and he suggested the point which he had just mentioned as one to which the funds of that Society might usefully be applied. The subject seemed to him to be such a large one that no private individual could undertake it. Certainly Mr. Andrews had made a most praiseworthy attempt to do so, and he had doubtless done so out of his own private funds, as well as giving his time.

He would now point out some of the apparent anomalies which he observed in the table showing the increase of rigidity of axles under flexion strain at a temperature of 50° F., Table II, Set 1. The third bend showed an increase of rigidity of 16·6 per cent., and the fourth bend showed no increase of rigidity. The sixth bend again showed an increased rigidity of 16·67 per cent., and at the sixth bend the rigidity went back to the normal. Every alternate bend gave an increased rigidity, and those between showed none. Without throwing the least doubt upon the experiments, he confessed that he could not understand the reason of such results. A similar anomaly existed in Table VIII. The fifth bend showed an increased rigidity of 183·04 per cent., and the next went back to 99·65 per cent., or the same increase as in the third experiment. Then the next one went to 199·65 and the next one went back to 99·65, and so forth. The twelfth bend went back to the same amount of increase as in the third bend, viz. 99·65 per cent. Then in Table XVI., Set 12, it was found that the first impact on the axles produced a deflection of 4¼ inches, and the second impact exactly the same. The third impact produced 4 inches of deflection, the fourth the same, and the fifth the same; so that there was apparently no increase of rigidity after the first blow, but rather the reverse. It seemed somewhat strange that there should be a reduction of rigidity after the second push. He had only noticed a similar result in the case of springs when strained within the elastic limit. He had not had time to go into the paper one-hundredth part as much as it deserved, but he had no doubt that Mr. Andrews could satisfactorily explain the anomalies.

Mr. W. G. Kirkaldy said he wished to thank the author for the information which he had given on the subject. The paper had been exceedingly interesting to him. He was especially interested in examining the question from the stand-point of axles which had been in service, and for that purpose he was trying to obtain some representative axles from which he fully believed far more could be learned than from many tests upon new axles, although that of course was also of vital importance to ensure good quality.

At present it was a hobby with him to get hold of some axles which had done a high mileage, and on the other hand, some which had been unfortunate and had failed at a low mileage. By minute experiments upon those, much valuable data would be obtained to guide engineers as to the best grade and quality of steel, &c. He thought, moreover, that engineers should give great attention to the question of form. He had an idea that they might try axles with the centre portion reduced more than at present to give a greater difference in size between the ends and the centre; or, if it were not deemed wise to reduce the centre portion, that the ends in the wheel-seats should be enlarged. The flexion which took place seemed to be all located at the inside of the wheel bosses, or at any rate it was very marked there, and he trusted that by altering the relative proportions the flexion might be spread over a wider area, and thus prevent the localisation of deflection which was so very detrimental. That the concentration of flexion was very detrimental he had proved by a series of experiments upon a broken axle, which had yielded most interesting and important information, and he trusted that locomotive engineers would help him to carry the investigations further.

Steel seemed to have gained a bad reputation in some quarters. He thought that the form of axles had something to do with that state of affairs. Steel being a very sensitive metal to deal with, if it were not used under favourable conditions it would give unsatisfactory results; in some circumstances giving way rapidly. That brought him back to the question of form, and as to whether the design of axles (as well as many other parts of engines) could not be distinctly improved.

With regard to iron, he had known of shafts working for a long time, even with a flaw in them. The flaw might penetrate to a certain extent until it came to a lamination where it might be arrested, and so run for a long time. That was a point in favour of iron. The structure of steel was quite different, and when once a flaw, however minute, was started, it would go on spreading more or less rapidly, and nothing would stop it. He believed that the progress or development of those flaws varied with the amount of carbon in the steel.

Mr. Perry F. Nursey said that, being familiar with the many years of laborious research by Mr. Andrews in connection with the present subject, he wished to express his high appre ciation of the paper just read, which he regarded as a crowning effort on the part of the author, and for which the Society was under a special obligation to him. The members in general could hardly be aware of the enormous amount of trouble and expense which Mr. Andrews must have incurred in preparing the paper, but they would realise it when it was published in the 'Transactions,' where it would form a most important standard of reference. It represented another phase of the question of fatigue of metals, and what he was about to say might perhaps appear somewhat trivial in comparison with the paper, but it might also be interesting. It related to the performance of a cheap American clock, made by Gilbert, of Winchester, U.S.A., which he purchased in 1863 for a few shillings. In 1893 he took some notes with regard to the clock, and those would show how metal would withstand fatigue under certain conditions. The clock in question made 172 ticks or vibrations per minute. That yielded for the period of 32 years—that was, to the present time—2,794,876,640 vibrations. The clock, being only a twenty-four hour one, had to be wound up daily. The number of windings had been 11,680 in the 32 years. The spring was still sound, and the whole machine was good. About twelve or fifteen years ago the clock was going a little sluggishly, and he took the works bodily out of the case and boiled them and put them back again, since when it had run well. About eight years ago it was going sluggishly again, and he sent it to a clockmaker to have it cleaned, and it was now going as well as ever it did. That was an example of what metal would stand under certain conditions of constantly alternating strain, and was also a testimonial to American clockmakers.

Mr. ANDREWS, in replying upon the discussion, thanked the meeting for the very courteous way in which they had received the paper, which it had afforded him great pleasure to present. It was cheering and encouraging to the pioneers of original research in any science to meet with the appreciative sympathy of others in their own profession. The deeply interesting remarks which had been made in the discussion of his paper had opened up such wide fields for further research that many years would be occupied in the investigations necessary to enable him to answer with confidence the points which had been raised. For that reason he felt it impossible to fully reply on the present occasion, but he would offer a few observations.

Mr. Beaumont appeared to have some doubt as to the interpretation of the results of a microscopic examination of iron and steel. After long experience, and years devoted to the careful microscopic study of the ultimate structure of metals, he (Mr. Andrews) had found the microscope an invaluable instrument for correctly studying the crystalline structure of iron and steel and the physical effects of temperature, &c., thereon; but it required special knowledge and skill to accurately interpret the results. But with accurate observation microscopic results were fully reliable. He considered that Mr. Beaumont's remarks were of great importance with regard to the effects produced by the rapidity or otherwise of the application of stress as well as the intensity of its application.

He considered that segregation caused the uneven distribution of the normal carbide of iron areas in steel axles. He had examined many steel axles and considered that the structure of steel axles was frequently very non-homogenous. The micro-segregations frequently produced numerous internal growing flaws. Steel increased in tensile strength with the percentage of combined carbon up to the carbon saturation point, but for either axle, rail, or tyre service it was very unsafe to have a steel of a high percentage of combined carbon, as high carbon steel was apt to be brittle. He was happy to say that his investigations had yielded some practical as well as scientific results, and had enabled him to arrange a mode of manufacture which would fit axles for safe use under varying climatic conditions. That was "something accomplished, something done" in the interests of the public safety in various lands. At his Wortley Iron Works, near Sheffield, he was able to produce wrought-iron axles suitable for the hot climate of India, or equally adapted to the severe cold of Canada, Russia, or other countries of low winter temperature. He had supplied the Canadian Pacific Railway with wrought-iron axles for the passenger cars, which were especially adapted to the varying climatic changes of that country. He was called upon to do that in consequence of the serious accident on February 5th, 1891, on the Schrieber section of the line, caused by the failure and sudden fracture of a Siemens steel axle (not, however, of his, the speaker's, make), to which he had alluded in the paper. Thus, where steel axles had failed he had supplied wrought-iron ones, and the results had been very satisfactory. He mentioned that matter, not by way of boasting, but to show how his investigations had been turned to practical account in producing wrought-iron axles best suited to resist the influences of climatic changes, a matter of more importance than was generally supposed. Since the year 1881 he had supplied a large number of iron axles for the Grand Trunk Railways of Canada, which were running satisfactorily, and not a single failure had occurred. Similar good records applied to iron axles which he had supplied for the railways of Great Britain and other countries.

In reply to Mr. McLaren's questions, he considered that not only axles, but steel tyres and rails, increased in rigidity and consequent brittleness under the constant concussion incidental to their wear. He had evidence to show that the journal wear of good iron axles was better than that of steel ones, and that in reality there was less liability to heated necks with iron than with steel axles. Moreover, iron axles possessed many points of advantage over steel axles in regard to safety. He approved of the suggestion which Mr. McLaren had made for doing away, if possible, with the torsional causes of fracture. At present, torsion was the worst enemy of axles.

Mr. Barker's suggestion for the study of the effect of smaller stresses would lead to useful results, as that was a matter of considerable importance, for, as the Scotch proverb says—

> "Mony mickles mak a muckle."

A study, therefore, of the influence of minute stresses on railway material would prove of great utility. The apparent anomalies alluded to by Mr. Barker in connection with the increase of rigidity at the different temperatures should receive further study, and until that was done it would be premature to attempt an explanation. The results recorded were, however, the actual facts observed in the course of the experiments. He had laid before the meeting the effects of strain, and he hoped on another occasion to be able to deal with the effects of stress. There was a vast difference between the two things. The anomalies to which Mr. Barker had alluded had puzzled him (the author) as much as they had puzzled Mr. Barker. Perhaps, from a further study of those anomalies, some most interesting results might ultimately be obtained. The anomalies indicated the necessity for further investigations in order to clear up matters which it was now difficult to understand. The great point in original investigations was to observe actual facts, and leave theories to take care of themselves. A man who began an investigation with his mind previously biassed by a theory would probably arrive at unreliable conclusions.

He highly appreciated the suggestion made by Mr. Kirkaldy to test old axles of known life history, and he was pleased to know that he (Mr. Kirkaldy) was working in that direction. He anticipated valuable results from such experiments. He was glad to know that Mr. Kirkaldy's experience, and the experience of others, confirmed his own as to the general unreliability of steel for axle service. With regard to the size of railway axles, he could see what Mr. Kirkaldy had in view, but he scarcely felt inclined to accept a reduction in size.

Mr. Kirkaldy said that he proposed to increase the diameter at the ends.

Mr. Andrews said that would alter the case, and that he had not at first quite understood Mr. Kirkaldy's meaning. He now understood that Mr. Kirkaldy wished to retain the present size of axles, but to increase the boss. He quite agreed with that suggestion, and he believed that the change would tend to safety. He should prefer, however, to go a little further, and increase the thickness of the axle as a whole. He was now speaking of railway wagon and carriage axles. The Board of Trade regulation required for those a diameter of 4½ inches in the middle. In the old days axles averaged from 3½ inches to 3¾ inches in the middle. He saw no harm whatever, but rather an advantage, in making axles 4¾ inches in diameter in the middle. There would be a small increase in the weight, but that would be far outbalanced by the advantage gained in point of strength.

As to the effect of flaws in steel axles, the presence of a flaw in steel axles would cause a fracture right across, as in a piece of ice or glass, in consequence of the crystalline structure of the material. In the case of an iron axle, which was made up of a number of welded pieces, a flaw would only extend to the next weld junction, leaving the remainder of the axle intact. The line of cleavage did not run through the forging, as in the case of steel. That fact formed an element of safety in iron axles which was absent in steel ones.

Mr. Nursey's marvellous figures with regard to the old clock interested him very much. He (the author) had made a calculation of the approximate number of crystals in a railway axle. He found the number of primary crystals to be 2,313,178,313, and the number of secondary crystals 1,564,000,000,000, a number which extended to thirteen places of figures. That was the approximate total of the ultimate crystals composing an ordinary railway axle of iron or steel.

He felt very grateful to his old friend, Mr. Nursey, and others for their kind remarks and criticisms on his paper, and he desired again to express his thanks for the kind reception it had met with.

Fig. 1.

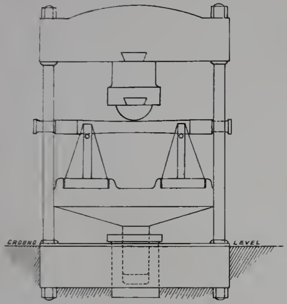


Fig. 2

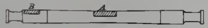


Fig. 3.

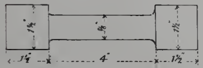


Fig. 4

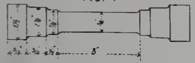


Fig 5.

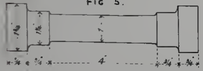


Fig 6

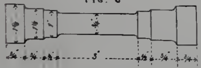
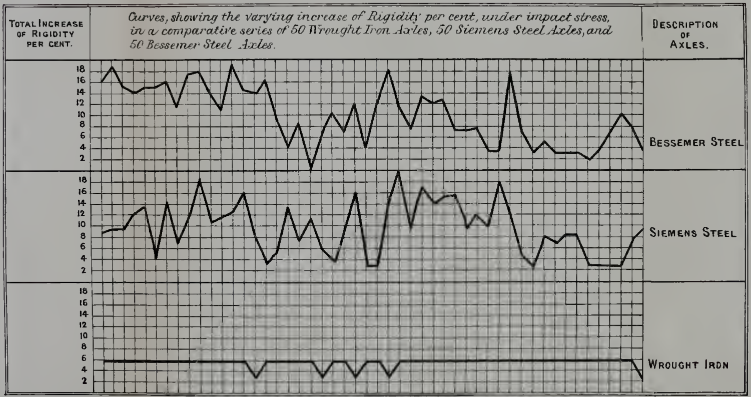


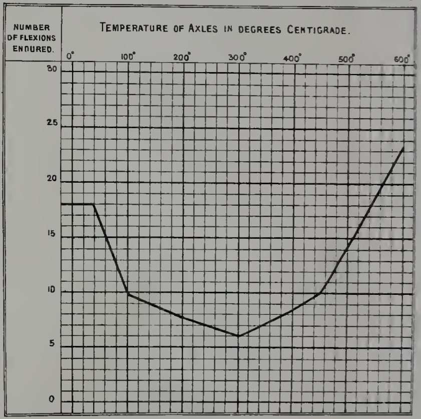
Fig. 7.



The Steel axles showed a greatr and more variable percentage increase of rigidity than the Iron axles = Temperature of the Axles. 50° F, or 10°. C.

Fig. 8.

Minimum Flexion Resistance Point in Railway Axles and the Effect of Temperature on the endurance of Flexion of Axles



E & F N. Spon, London & New York.

THE EFFECT OF STRAIN ON RA

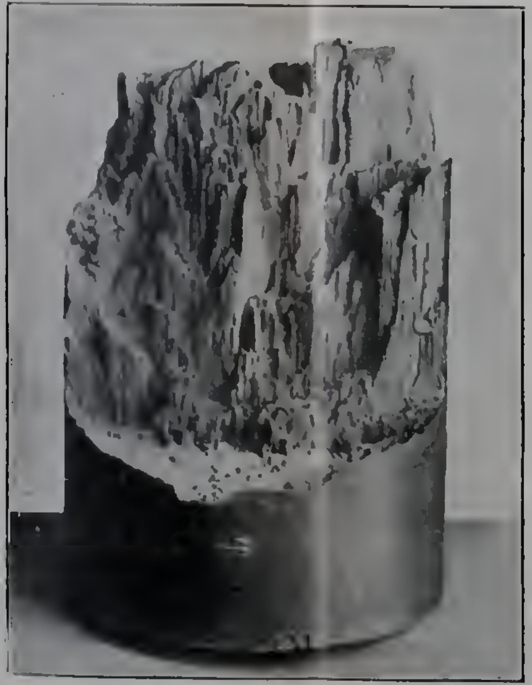
FRACTURES OF WROUGHT IRON RAILWAY AXLES BY BENDING BY HYDRAU

DIAMETER OF MIDDLE OF AXLES, 4⅜ INCHE

AXLE No. 52.

Set V., Table VI.

WARM TEST.

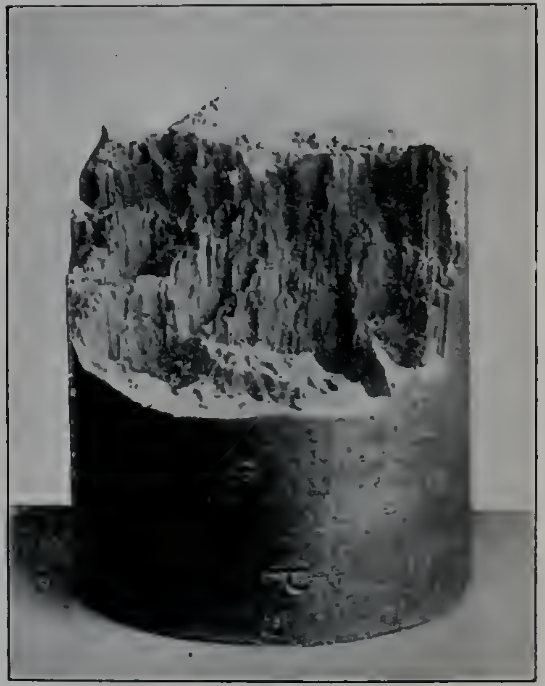


Temperature of Axle, 300° C.

AXLE No. 53.

Set V., Table VI.

WARM TEST.

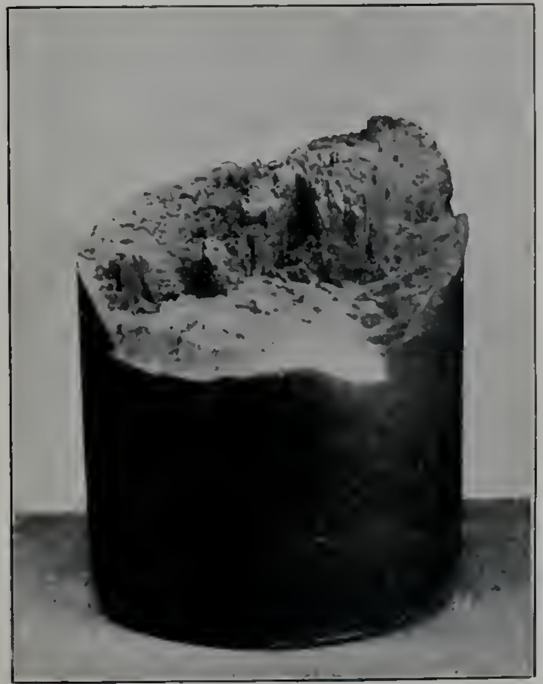


Temperature of Axle, 300° C.

AXLE No. 54.

Set V., Table VI.

WARM TEST.

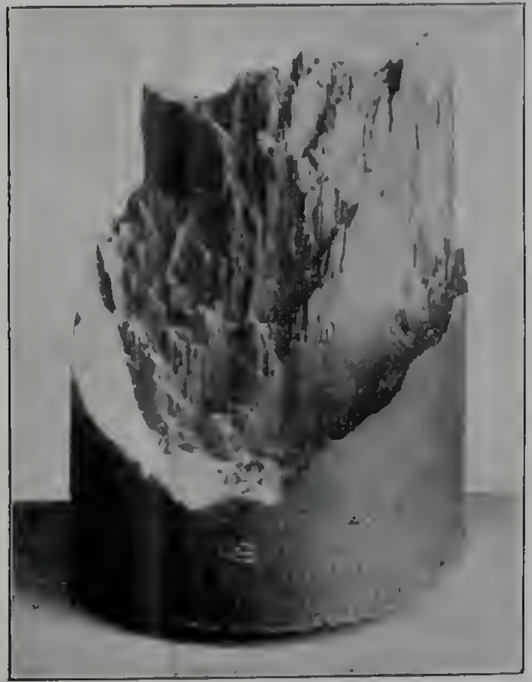


Temperature of Axle, 300° C.

AXLE No. 55.

Set V., Table VI.

WARM TEST.



Temperature of Axle, 300° C.

AXLE

Set V.,

WARM

Temperature of

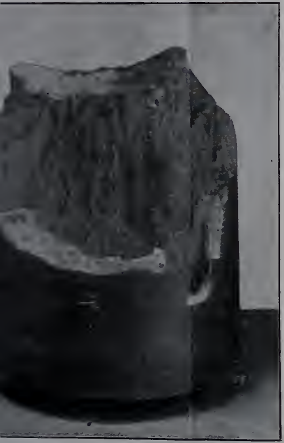
N RAILWAY AXLES.

PLATE II.

Y HYDRAULIC PRESSURE AT VARIOUS TEMPERATURES.

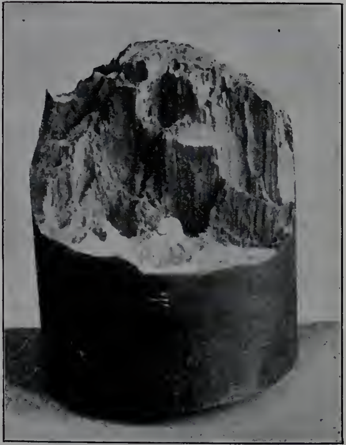
ES, 4⅜ INCHES.

AXLE No. 56.
Set V., Table VI.
WARM TEST.



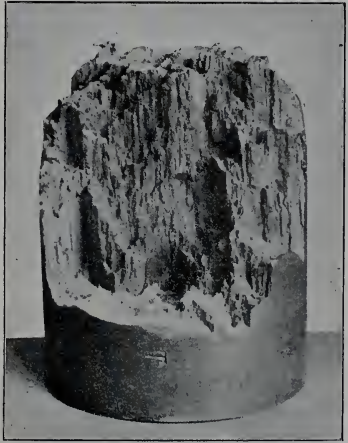
Temperature of Axle, 300° C.

AXLE No. 58.
Set V., Table VI.
WARM TEST.



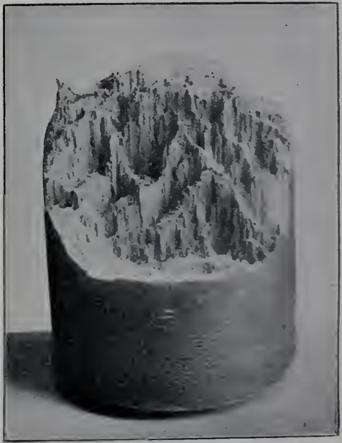
Temperature of Axle, 300° C.

AXLE No. 59.
Set V., Table VI.
WARM TEST.



Temperature of Axle, 300° C.

AXLE No. 60.
Set V., Table VI.
WARM TEST.



Temperature of Axle, 300° C.

THE EFFECT OF STRAIN ON

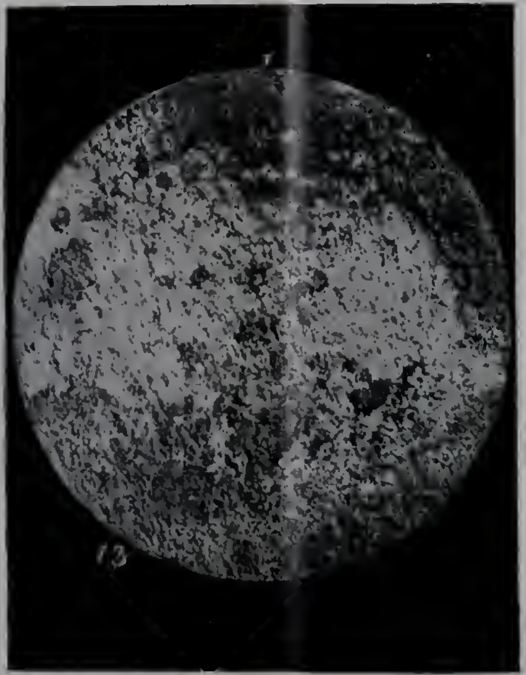
FRACTURES OF WROUGHT IRON RAILWAY AXLES BY BENDING BY HYD

DIAMETER OF MIDDLE OF AXLES, $4\frac{3}{4}$

AXLE No. 13.

Set II., Table III.

COLD TEST.

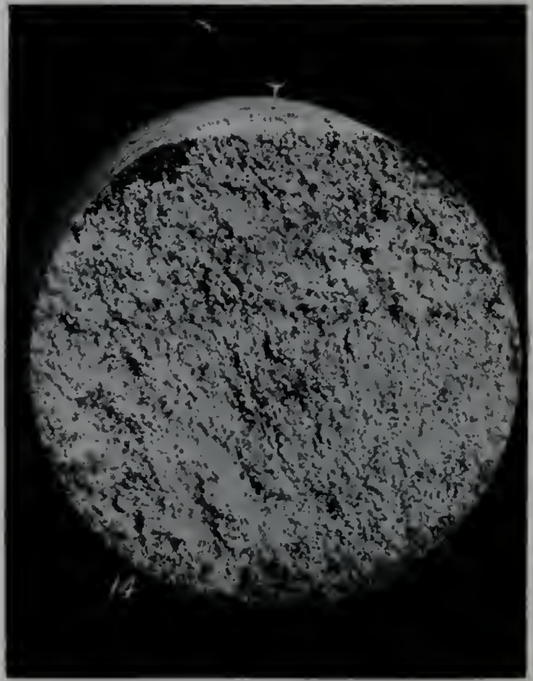


Temperature of Axle, −18° C.

AXLE No. 14.

Set II., Table III.

COLD TEST.

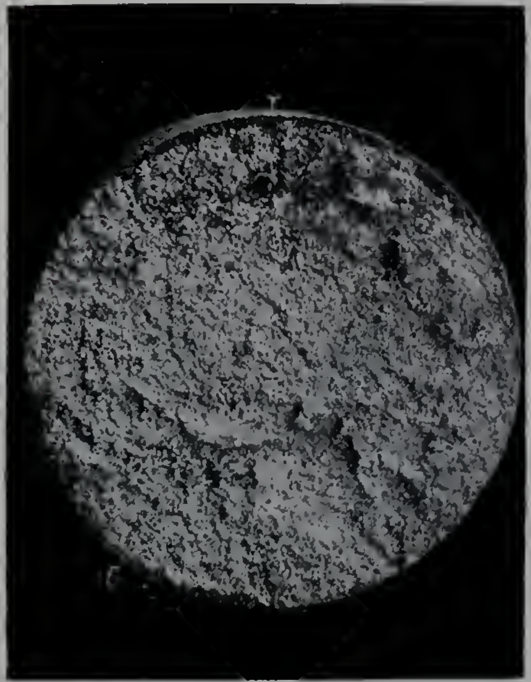


Temperature of Axle, −18° C.

AXLE No. 16.

Set II., Table III.

COLD TEST.

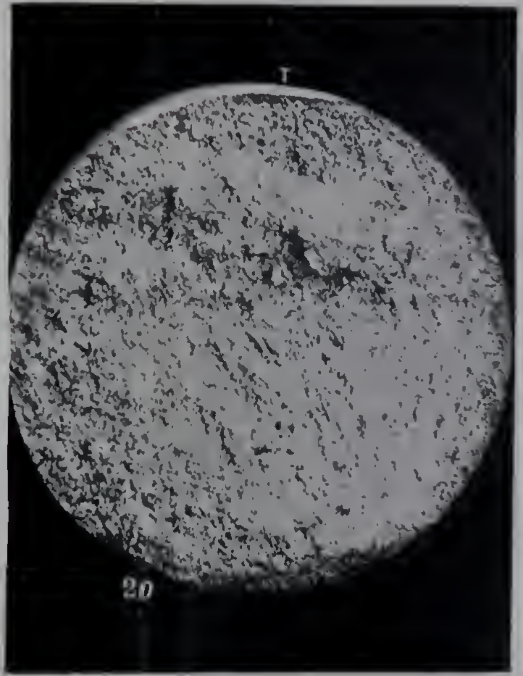


Temperature of Axle, −18° C.

AXLE No. 20.

Set II., Table III.

COLD TEST.



Temperature of Axle, −18° C.

S

Temper

FFECT OF STRAIN ON RAILWAY AXLES.

PLATE III

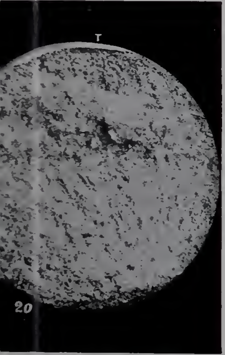
AILWAY AXLES BY BENDING BY HYDRAULIC PRESSURE AT VARIOUS TEMPERATURES.

DIAMETER OF MIDDLE OF AXLES, 4⅜ INCHES.

AXLE No. 20.

Set II., Table III.

COLD TEST.

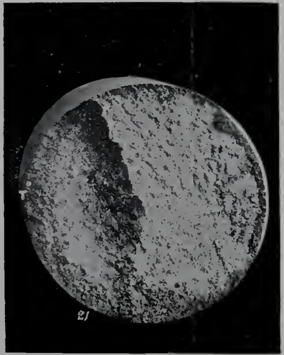


Temperature of Axle, −18° C.

AXLE No. 21.

Set II., Table III.

COLD TEST.

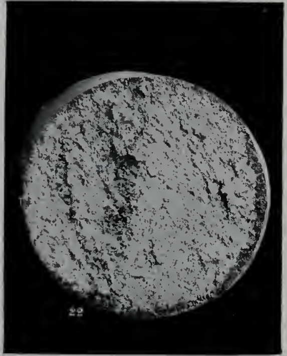


Temperature of Axle, −18° C.

AXLE No. 22.

Set II., Table III.

COLD TEST.

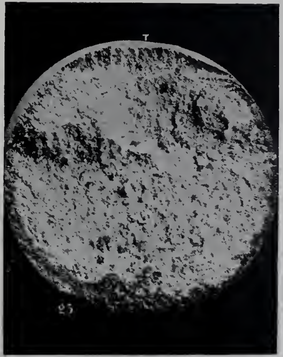


Temperature of Axle, −18° C.

AXLE No. 23.

Set II., Table III.

COLD TEST.

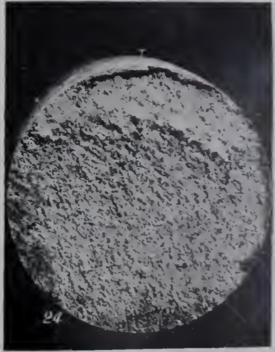


Temperature of Axle, −18° C.

AXLE No. 24.

Set II., Table III.

COLD TEST.



Temperature of Axle, −18° C.

December 2nd, 1895.

WILLIAM G. PEIRCE, President, in the Chair.

VENTILATION AND WARMING.*

By William T. Sugg.

Three can be no doubt that on the important subject of ventilation and warming there exists a great diversity of opinion amongst architects and scientific men who devote themselves to its study. They do not, probably, differ on the main fundamental principles of ventilation and warming, but they differ very much on the methods of putting those principles into practice. These differences result largely from the fact that every building has in this respect its own special requirements arising out of its situation, construction, and the uses to which it has to be put. These special requirements evidently render it impossible to lay down hard and fast rules of procedure suitable for all cases. It is, therefore, clearly necessary, previously to arranging any scheme, to make a careful examination of the conditions required to be fulfilled, taking into account the position of the building and the natural circumstances which may materially affect, either beneficially or prejudicially, the working of that system to be finally adopted.

Although this statement has the air of being a truism, yet the number of examples that might be cited in which the requirements have to fit themselves, if they can, to cut and dried systems which have been found to work well in some other places, in which, however, the circumstances are not the same, is so large that the reiteration of such a truism at the beginning of this paper is amply justified. As a rough and ready illustration of the unsuccessful results derived from the attempt to make the requirements fit themselves to the scheme of ventilation and warming, the following example, which may be very easily verified, because of its commonness, will suffice.

In some of the most lavishly decorated rooms of the most modern first-class restaurants and hotels in London and the provinces, where dinners are served on a tolerably large scale, the system of ventilation which provides for the free admission of fresh air by the open doors and windows, and even by the chimneys in summer time, meets the requirements of those youthful guests who, when the time for smoking arrives, lean back in their chairs and enjoy at the same time their havannas and the cool breezes which waft the smoke about in a variety of curious twists and curls, very interesting to watch if one is a student of ventilation.

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* The Society's Premium was awarded to the author for this paper.

But very different is the effect of this system upon another class of diners, even under the same atmospheric conditions. Unlike the youthful diners, they are more advanced in years and have less natural protection, and there is with them no feeling of revelling in the deliciously cool currents. On the contrary, the imperative order to close the windows and doors, which is issued early in the evening, brings the whole system of ventilation to grief. The guests are dependent, for the fresh air they breathe, upon the opening and shutting of the doors as the waiters go in and out of the room—and by the time smoking commences the air of such rooms has become dangerous to health. The smoke no longer curls in fanciful wreaths about the room, but hangs in a heavy inert cloud, occasionally moved a little by opening or shutting of doors or the surreptitious opening of a window by one of the waiters for a very short time. The smoke shows clearly enough that there is practically no change of air in the room, but that the vitiated air, cooled by contact with the ceiling, is hovering round the heads of the guests, who must breathe it over again. Is it to be wondered at, that colds and a general feeling of depression so frequently follow a so-called enjoyable evening spent in one of these highly decorated but insanitary rooms.

In churches, chapels, schools and public halls, much more elaborate and costly systems, designed on very much the same lines, have resulted in similar failures, and at last, with the advent of the electric light, which gives off no products of combustion, and no heat to warm the ceiling, all systems of ventilation have been in a great number of cases entirely abandoned, and the *summum bonum* of human happiness and comfort under the head of ventilation and warming has been supposed to be arrived at by the adoption of the simple system of no ventilation and no warming at all. It would not be difficult to find many, perhaps hundreds of large electric-lighted dining halls and reception rooms within a mile or two of Charing Cross, in which there is neither inlet for fresh air nor outlet for vitiated air except the doors. So then there is evidently a kind of dead level of agreement amongst the architects of these buildings, as to the common principles of ventilation and warming—they will have none of it.

Where there is electric light and no ventilation the guests are supposed to be quite able to do their own warming; more especially if, in cold weather, a few petroleum lamps of high heating power and voracious appetites for oxygen have been placed in the rooms some time before the dinner or other function is to take place. A few bottles of oxygen ought to be provided along with the wine to complete this admirable system. These "fin de siècle" methods of ventilation and warming might be possibly improved by grafting on them some deliciously quaint modification of the early Indian wigwam system. Leaving these till the public condemns such crude schemes, it will be convenient to at once attack the question of practical and successful ventilation and warming, by describing the method adopted at the present moment for warming and ventilating the Houses of Parliament, with a view of showing how the principle of suiting the scheme of ventilation and warming to the requirements of the building, as well as the adaptation of its structural advantages to the same end, has been worked out during a great number of years to an eminently successful issue. The author is strongly of opinion that in describing the present system in use there, he will be taking the shortest route towards the explanation of the best and most practical principles upon which ventilation and warming can be carried out in other buildings, so as successfully to meet the requirements of the general public.

It is not pretended for a moment that the general public trouble themselves with the details of ventilation or warming, but what they know they want is sufficient fresh air and sufficient warmth, to enable them to do their work, or enjoy their pleasure, without their health being endangered either in summer or winter. They are not, as a rule, in a position to constantly roam over the highlands, or sail over the sea, where the air is always pure and invigorating, but in following their ordinary avocations are obliged to work under conditions which would not only render them liable to various forms of disease, but would diminish their energies and finally shorten their lives, were it not for those who have made it their pleasure as well as their business to study the laws of nature, in regard to the health of towns. To such, the work of ventilating and warming, as carried on in the Houses of Parliament, has always been of the greatest interest. The highest intellects in science and medicine have given their minds to work out this system, and, although it must be admitted, they have not always had the satisfaction of seeing their ideas successfully wrought out, yet even in their failures they have pointed out the way to success. It is only just to say that the science of ventilation and warming, as it is understood to-day, is very deeply indebted to the labours of those who have, during many years past, carried out the work of warming and ventilating the Houses of Parliament, and the success of their work has awakened the admiration of both English and foreign engineers who have seen and profited by it.

The first thing which impresses itself on those who are practically engaged in ventilation and warming, is the great variety of the requirements of the Houses of Parliament under these two heads. To commence with, the Debating Chamber of the House of Commons (see upper part of Fig. 1) has about 165,000 cubic feet of air space when there is no one in it. Within this Chamber it is imperative to maintain a suitable temperature both day and night at any time of the year when the House is in session, and an ample and practically pure supply of air, which shall be sufficiently moist and free from fog, smoke or soot. It has been ascertained by careful consideration and the experience of many years, that the volume of such air supply is required to average about 30 cubic feet per minute, more or less, according to the condition of the House during debates, for every member who is present in the Debating Chamber, and rather less per head in the lobbies.

The number of members in the Debating Chamber, and also in the lobbies, is constantly changing. A speaker, such for example, as Mr. Gladstone, Mr. Balfour, or any other party leader who possesses the ear of the House, gets up to speak on some important subject, and the chamber is rapidly filled. Some 400, 500, and occasionally over 600 members crowd in to hear the speech, or to vote, in answer to a telegraphic message sent round the buildings. There are, besides, the strangers in the galleries, and these with the members may bring up the number to 1000. For an hour, or two, or three, or even more, the chamber must be overcrowded. Then there comes a rapid thinning of the numbers, either because of the dinner hour, or because some member has caught the speaker's eye who has not the power to interest the whole body of members, and barely forty may be present, where just a quarter of an hour before there were five or six hundred. In addition to these difficulties, the late and all-night sittings demand very careful attention and management on the part of the ventilating staff. It must be borne in mind, that the House of Commons is not a place in which experiments on ventilation can be tried with impunity. It would be quite possible for a person not well acquainted with the work to fail to keep a suitable temperature in the Debating Chamber during an all-night or a late sitting, and the result would be disastrous to the health of many of the members.

The ingress of warm, fresh air, constantly flowing through the Chamber, must be very deftly managed, so that it corresponds to the condition of the bodily temperature of the members. The continual maintenance of such a large upward moving air supply at one fixed temperature, say 63° F., would, in a short time, gradually lower the temperature of the body by continually sweeping off the heat from it, and produce a chill which might even be fatal to some constitutions. But the experience of many years has taught the officers of the ventilating department that the temperature of the air supply must be gradually increased, having due regard at the same time to the conditions of the external atmosphere, as the night wears on, until in the early morning it may be as much as 74° or 75° F., or even more. The debates may be comparatively dull and listless, or they may be quite the contrary; there may be many divisions or there may be none. All these circumstances must be weighed and allowed for in the changes made in the volume and temperature of the air supply.

It would be a comparatively easy matter to keep a constant temperature in the Debating Chamber of, say, 63° F. in summer and in winter; but it would be a most unsatisfactory, and probably a dangerous thing to do. A member of Parliament arriving in the Debating Chamber after a sharp walk in ordinary wintry weather, when the temperature is at, say, 40° F., or from a walk or drive on a sunny day, when the thermometer stood at 80° F. in the shade, would find the fixed temperature of 63° F. not at all suitable, after he had been supplied with it at the rate of about 30 cubic feet per minute for an hour or so. The difference between the temperature of the inside of the Chamber and that of outside air in the streets must not be too widely divergent if practical and satisfactory ventilation is to be maintained. From what has been said, it will be evident that a special and most intelligent system of ventilation and warming is required in the Debating Chamber and lobbies of the Houses of Parliament.

The method at present adopted for renewing the air and warming the Debating Chamber itself is to supply the fresh air, previously cleansed, warmed, and properly moistened in an equalizing chamber situated beneath the floor of the House (see Fig. 1), but equal to it in area, through a number of perforations fairly distributed all over the area of the Chamber. The floor is covered with a string-netted carpet, which offers no obstruction to the incoming air, and does not retain dust. The aggregate area of the whole of these perforations is equal to about one-eighth of the area of the Chamber. About half of these holes are in the gangway, and the other half are at different levels above the floor, in suitable places, so as to distribute the air fairly over the whole Chamber, and avoid the possibility of any of the members breathing the vitiated air over again. It will be seen from Fig. 1, which shows at a glance the entire system of ventilation, that such an arrangement must have the effect of supplying this fresh air in considerable volume at an almost imperceptible velocity, and, therefore, without draught.

The extraction of the vitiated air is effected by aspiration through a large number of concealed openings contrived all over the ceiling, so that it may be as regular and uniform as possible from every part of the Chamber, above the ceiling (see Figs. 2 and 3). The ingress of fresh air is slightly assisted to the extent that there should never be sufficient suction from above the ceiling to encourage the entrance of air from the doors opening into the lobbies of the House, and to ensure that all the supply of air shall come through the proper channels provided for the purpose, and no other. It must be evident, on consideration of the system in use, that in the Debating Chamber there never could be such a thing as pressure, as that word generally implies. The rate of the velocity of the entering air is so small as hardly to be perceptible. The great number of perforations, which occupy, as before stated, an area equal to about one-eighth of the entire area of the Chamber, allows a large volume of air to come in so easily that a very much larger volume than would ever be required could be supplied without perceptibly increasing the velocity over this normal rate.

The always considerable volume of warmed and purified air gradually ascends from the floor as it gets warmed and vitiated at a very low velocity at first, increasing its speed, however, as it nears the ceiling line, carrying with it the comparatively small quantity of heated vitiated air given off from the assembled members. The radiant heat from the bodies and steam from the breath of members would, if there were a fairly good attendance, slightly increase the heat of the chamber just above their heads, and cause it to take a more rapid vertical direction clear away to the ceiling. Under the circumstances, the general temperature of the House, just above the heads of the members, must always be so much below the temperature of the breath and the heated air given off from the assembly, that the vitiated air would always be able to rise through the superabundant supply of fresh air to at least very near the ceiling level. Once there it has no chance of returning towards the floor.

The natural upward rising of the emanations of the body are very graphically shown by placing a man in the full glare of a powerful light, such as the electric light, and projecting his shadow on to a flat white surface. The electric light not only projects the shadow of the man on to the screen, but also the shadow of the atmosphere. The difference in the density of the heated and the cold air is also shown; the highly refrangible rays of the electric arc light pass much more easily through the rarefied than through the cold air, and show themselves in more or less white streams, according to the degree to which the air is heated. As the heated air gets cooled down again to the same degree as the cold ambient air, these whiter streams gradually disperse, and, descending towards the ground, disappear. Of course, this descent of the vitiated air can only occur when the air above the head of the man is cold enough to cool down the heated products to about its own degree before they can get to the ceiling.

It is, therefore, important that the air of chambers should always be sufficiently warm above the level of the head to encourage ascent of the vitiated air to the ceiling. From the level of the ceiling it should be taken off at such a rate as will prevent the accumulation of heat beyond 84° at any time. If there should be such an accumulation of heat as to raise the temperature of the upper stratum of air to 82° F. within, say, 7 feet from the ground, the emanations from the lungs and body will not rise through that stratum except at such a slow rate of movement as to be practically equivalent to no ventilation at all. Therefore the vitiated air must be breathed over again in a more or less diluted state, according to the larger or smaller quantity of air which can get into the room below the hot level. Nausea, headaches, faintings and a general lowering of the rate of the heart's action, even in the case of strong persons, is the result of breathing vitiated air. Sometimes even it is a vehicle for spreading infection. Thus the primary point to be secured in any good scheme of ventilation is to assist nature in causing the emanations from the body and lungs to rise to the ceiling, and in carrying them off from thence so that they cannot be breathed over again. In the House of Commons Debating Chamber the aspirating power which draws off the vitiated air is produced first by a number of Argand gas burners, which serve to light the House (see Fig. 3). These are placed over each one of a number of squares of glass, which form the central longitudinal portion of the ceiling. Each square of glass is 3 feet square, and as it does not set quite down into its frame, but is so placed as to leave an inch space all round it, there is a sufficiently large aggregate area in the ceiling panels and side panels of the roof to equal about 200 square feet, and to allow the vitiated air to pass from the Debating Chamber into the roof chamber. From thence it is drawn by aspiration into a large flue which descends into the basement, and finally finds its way to the clock-tower shaft. At the base of this shaft, which has an area of 64 square feet, is found the motive force, which is capable of putting in motion a column of air more than 200 feet high by about 64 square feet area, or a total of about 12,800 cubic feet, at a velocity of about 5 feet per second, more or less, the rate of speed varying with the increasing or decreasing of the fire, as may be desired, according to the amount of work required to be done at the time.

This utilisation of the powerful shaft of the clock tower to produce an upcast sufficient for the extraction of the products of combustion and vitiated air from all the rooms, offices and chambers of the House of Commons has been very simply and scientifically arranged. A large iron grill, rather less in area than that of the shaft itself, is fixed at about 4 feet from the ground, so as to allow of sufficient air passing under it to keep a layer of coke freely burning on it. The size of the coke fire regulates the velocity of the upcast. The heat of the burning coke (ordinary gas coke) produces an upcast more or less rapid as the fire is increased or diminished, or as the external atmospheric influences affect the draught either one way or the other. In cold winter weather the draught with the same amount of fire is better than it is in hot summer, principally on account of the tendency of the enclosed courtyards in hot weather to act as upcast flues, and to work in some degree against the clock-tower upcast. This, when it does take place, is easily remedied by slightly increasing the fire in summer. By this extremely simple method the whole of the heating power of the coke is converted directly into force. The saving of labour in looking after the fire as compared with what it would cost supposing steam, gas, electricity or other motive power were used in combination with a fan or other contrivance, is enough to render this method the cheapest and best way of putting so large a body of air at low velocity into motion, with the help of the clock-tower shaft. If there were no such tower as there is at the Houses of Parliament, steam would have to be employed, with a more costly and troublesome arrangement to look after. One great advantage of the coke-heated shaft is that the lining of the furnace and shaft throws out a great volume of heat for a very long time after the fire is out, while the upcast action of the shaft will continue until the walls are cold.

In any case a coke fire is best for producing an updraught for ventilating purposes, in large asylums and buildings which are generally designed with large and high ventilating shafts, because it gives the least trouble to keep it going, and will not bring the whole system of ventilation suddenly to grief, as when a mechanical arrangement is suspended from any cause, such, for example, as the failure in the water supply to a boiler, &c. Let it be clearly understood, that the author does not condemn the system of ventilation by fans or other mechanical contrivances. They must be used sometimes, but they are neither necessary nor suitable in a great number of cases. For instance, when electric fans are put into windows, one or more blowing fresh air into one side of a room and a like number supposed to be extracting the vitiated air (sometimes, if they can, against the wind) on the other side, it cannot be said that this is a satisfactory method of ventilation. That very old inlet ventilator, the whirligig, so familiar to visitors to old inns and smoking parlours, is probably an improvement on this method because it does not produce such a disagreeable draught in letting in fresh air. The old high chimney-piece with its arch reaching nearly to the low ceiling of these rooms acts on a reduced scale very much like the shaft of the clock tower at Westminster as an extractor of vitiated air.

The supply of fresh air for the House of Commons is taken from the river front and passes down through the areas in front of the wall of the building (see Fig. 4). It is drawn into the basement gallery by means of a revolving fan, where it is moistened or cooled, when necessary, either by jets of water or by ice. This fan drives it forward at the requisite velocity, first through a screen of paperhanger's canvas or scrim, and afterwards through a filter having a surface of 1000 square feet, if the air is in any degree charged with fog. The filter is composed of two layers of cotton wool, each three inches thick, with about one inch of separation between each layer, so that the first or lower one takes out the principal portion of soot and smoke, and the upper one takes out the rest. The wool shows unmistakable signs of its effectiveness as a filter in the course of a fairly foggy day. When fully charged with dirt the wool has to be renewed (see Figs. 1 and 4). Having been cleansed, the air flows into the battery chamber above the filter chamber where it is warmed. The warming arrangements were designed by the late Sir Goldsworthy Gurney specially for the work of warming the various chambers, committee rooms, &c., of the Houses of Parliament.

It will be remembered that in the earlier portion of this paper it was pointed out that the whole of the warming and ventilation arrangements must be under immediate control, so that any suitable degree of temperature as well as any required volume of fresh air may be admitted into the Debating Chamber or other chambers at a very short notice, ranging probably from a few minutes to half an hour or longer. Only steam heating could accomplish this, but as the surface of the comparatively highly heated steam pipes ranges, according to the amount and pressure of steam let into them, from about 120° to 212° F., Sir Goldsworthy conceived the practical idea of converting at once the high heat of these pipes into a larger volume of air at a comparatively low temperature. To do this he prepared a number of zinc plates, about a foot square more or less as required, with a hole perforated in the centre, of such a size that the steam pipe could pass easily through them. He then soldered them on to the tube, spacing them off from one another about an inch, sufficiently to admit of the free passage of the air to be warmed betweeen the plates (see Fig. 5). Thus, by arranging the number and size of his plates he could obtain a great heating surface, and reduce the temperature of the steam pipes by conduction into the zinc plates, so that the air could be properly warmed without overheating it. He also found that by covering the range of plates, which he named a battery, with a cloth like a towel, the warming of the air could be stopped in a moment and resumed again by simply taking away the cloth. Thus, by the aid of a sufficient number of these batteries a full or diminished supply of air warmed to any required degree could be rapidly obtained. It is abundantly clear to any practical mind that no other system could give so complete a control of the temperature as to enable the requirements of the Houses of Parliament to be properly satisfied. After having been properly cleaned, warmed, and moistened, the fresh air ascends into the equalising chamber, situated just under the floor of the Debating Chamber, and communicating with it freely by means of the immense number of perforations before mentioned.

The time required for the passage of the air from the terrace on the river front, through the chamber, and away to the clock-tower shaft is very short; passing in rapidly at first and coming almost to rest as it passes through the Debating Chamber, into which it enters in a slow stream moving not faster at any time than 1½ foot per second, it increases in speed as it nears the ceiling line, and gets to its highest velocity as it rushes up the clock-tower shaft. A rather amusing illustration of the perfect ventilation of the Debating Chamber is occasionally afforded by the passage of a barge on the river along the front of the terrace, the said barge being loaded with gas tar or some other strong smelling material. If the wind happens to waft the spicy breeze just over the grating, down it goes, and in spite of cleansing and warming, it makes its unsavoury presence felt in the House for probably a minute, and then it is gone.

There are many who think, as the author once thought, that if the fresh air were taken from a high elevation, say the top of the Victoria Tower, for example, it would be purer than that taken from the ground level of the terrace or the river front. Although it might be the case in some places, it is not so at Westminster. Careful experiments carried out by Mr. Prim, the engineer to the Houses of Parliament in command of the ventilating, warming and lighting arrangements, have conclusively demonstrated that there is a far greater number of blacks per square foot of surface, collected on a blanket exposed to the air which passes over the top of the Victoria Tower, than on the same area of surface on the ground. He considers that the cleanest air is at about 40 to 60 feet from the ground at the Houses of Parliament. Probably that would be about the same anywhere in London, at least, that is the experience, generally, of the author. Air at ordinary high elevations, such as the top of the Victoria Tower or the clock tower, is generally charged with soot and sewer gas.

The Debating Chamber of the House of Lords and the Committee Rooms are warmed and ventilated on the same lines, excepting that in all these cases, the work being much more regular than in the Debating Chamber of the House of Commons, there being no sudden fluctuations in either the number of persons present or the hours of attendance, and, moreover, the hours being, as a rule, comparatively short, the arrangements do not require to be carried out quite in the same manner to ensure that degree of perfection which is attained in the House of Commons.

For buildings used for legislative and similar purposes the complete system of ventilation and warming which has been just described is eminently suitable. In planning out the ventilation and warming of new buildings on the same lines, doubtless some useful improvements would suggest themselves, and probably the sites and construction of these buildings might more effectively favour the application of a different system than does the low-lying situation of the Houses of Parliament. But in the very important work of school ventilation, although it would not be possible, from the nature of the construction and general planning out of the buildings, to carry out such a complete scheme as that of the Houses of Parliament, the requirements of a large school under the heads of ventilation and warming are not so very different from those of the committee rooms and other chambers in the Palace of Westminster. The most important principle which rules the scheme of the Houses of Parliament is equally if not more important in the warming and ventilation of schools, viz., that the vitiated air from the pupils must be induced to take a straight course up to the ceiling, and not have a chance of returning to be breathed over again. There are so many infectious diseases peculiar to the young carried into schools by the pupils, that without such a precaution the seeds of these diseases would be, and in fact are, in many buildings spread to an alarming extent. There is need for a superabundance of fresh air, but it must not blow in so as to cool the vitiated air and send it down about the heads of the pupils. It should be admitted in a great number of places all round the rooms at a low velocity, so as not to disturb the natural upward rising of the vitiated air towards the centre of the room as the cooler fresh air takes the place of the latter by the fact of its own heavier specific gravity.

The warming of fresh air and its admission through the floors is not always possible, and when it is so, it is not always desirable. When it is done by means of hot-water pipes laid under the floors, the dirt of the streets from the scrapings of feet walking over the gratings always makes this system objectionable. The system of warming by means of radiators placed round the chambers is much better, because it prevents the cooling down of the vitiated air by contact with the cold walls and windows, and its subsequent sinking down to the floor to mix itself with the fresh air. Besides this, the radiant heat is felt all over the room. The fresh air, if delivered in at suitable levels (generally from about six feet above the ground), through a sufficient number of funnelated openings, as shown in Fig. 6, will spread itself without draught all over the chamber, and displace the vitiated air, which will rise to the ceiling. Here, as in the Debating Chamber of the House of Commons, it must be carried off by aspiration, and there is no reason why the power for doing this work should not be obtained by similar means to that adopted in the Houses of Parliament. If the building is, by means of its construction, suitable for the purpose and large enough, the upcast may be produced by coke, and the chambers may be warmed by steam radiators on the Goldsworthy Gurney principle. If, on the other hand, the chambers are not planned so as to suit this scheme, the upcast to draw off the vitiated air from either one or more chambers as may be convenient, can be very easily produced by means of one or more gas-burners, properly regulated, so as to control the consumption and maintain it at any required point.

Fig. 7 shows an arrangement of aspirator which is a modification of some which were in use in ventilating some of the smaller chambers of the Houses of Parliament not connected with the clock-tower aspirator. It is fitted at the upper extremity of the shaft with a ventilator which creates a considerable up-draught, without the assistance of heat, whenever there is a wind blowing across its top. In a still atmosphere the gas jet induces an up-current, so that under any conditions of weather a continuous up-draught is secured. The top of the ventilator is composed of a number of tubes surmounted by a flat plate raised up above the tubes to a height more than sufficient to allow all the air which can possibly pass up the shaft to get away. The passage of a very slight wind across the tubes aspirates the air out of the top of the ventilator, and consequently produces an upward current in the shaft. As an example of what may be done by such an apparatus, a 4-inch shaft, 8 feet long, will aspirate, with the help of a jet of gas burning $\frac{1}{2}$ to $\frac{3}{4}$ a cubic foot per hour, upwards of 1100 cubic feet of air per hour in a still atmosphere, and with the further assistance of a wind moving across the ventilator at a velocity of $4\frac{1}{3}$ feet per second it will aspirate 3126 cubic feet per hour. A 6-inch similar cowl, with a burner consuming 4 cubic feet of gas per hour, will, in a still atmosphere, aspirate about 2500 cubic feet of air per hour, and with the assistance of wind moving at the velocity of 9 feet per second, it will aspirate 6480 feet per hour. Of course these results would be more or less altered by alterations in the barometric pressure and temperature of the atmosphere outside, as well as by the temperature of the room from which it was drawing the vitiated air. It will be noticed that it has been found necessary to guard the gas flame from the effect of vitiated air and uprush, by supplying it with an independent supply of fresh air. The same arrangement applied to smoke flues was patented by Mr. Johns and worked well, except that it had nothing to prevent down-draught in cold weather putting the light out.

These results show that for many class rooms these small-sized cowls would be sufficient, and they could be depended on to work in any weather. With moderate wind they would not require the gas to be burned, but the small quantity used would not be of great moment. Especially for the ventilation of w.c's. and lavatories the 4-inch or 6-inch cowls arranged as an inlet and outlet, as shown in Fig. 8, afford a most useful and effective means of ventilating generally most difficult and often dangerous places.

The Egyptian Hall of the Mansion House in the City illustrates a method of carrying out the main principles of the House of Commons ventilation and warming in a different way and in a less elaborate manner, but suited to the requirements of the building. The principal uses of this hall are for meetings, concerts, balls and dinners. The number of guests may be from 200 to 600 or 800. Its length is 80 feet, height 50 feet, and width 40 feet, and it contains about 160,000 cubic feet of air space when no one is in it. The length of time occupied by the various functions is generally from two to three hours, excepting when state balls are given, and then it may be six or seven hours. Some of these entertainments are in the summer and others in the winter, so that the work of warming and ventilating has to be carried on under a great variety of circumstances. The ventilation has been entirely carried out by the author, under the direction of the City surveyor, Mr. Murray, and is cited as an example of the adaptation of existing appliances to the requirements of the building. The warming of the building was already carried out in a very satisfactory manner by means of steam radiators placed at suitable intervals round the walls of the hall, the two principal ones being placed under the two great stained glass windows, one at either end of the hall. The hall is lighted by the electric light, assisted by three large sun-burners fixed in the roof.

In order to ascertain the movements of the air in the chamber, and to discover the source of the numerous currents of cold air which were complained of, it was found necessary to employ a couple of small balloons, each holding about a cubic foot of gas. These balloons having been filled were delicately balanced by means of a cork attached as a car, which might be easily reduced in size till the balloon would neither rise nor fall in a temperature of 64° or 65° F., 62° being the average temperature of the hall at about four feet from the floor. The balloons were then let go, one from each end of the hall, under the windows close to the radiators, which were in action. They both immediately took an upward course till they reached an altitude of about 15 feet, when they both took a downward course, meeting in the middle of the hall at the Lord Mayor's chair, into which they both descended, and finally got under the table, drifting slowly along till they got into some corner where there was no current of air. Several other trials resulted in very nearly the same course, but the balloons never went higher than about 15 feet, although the corks were still further lightened, which would have the effect of making them rise in cooler air than 62° F. It must be here explained that such a balanced balloon follows the currents of air very accurately, rising in air warmer than that in which it was balanced and falling in colder air, the speed of its falling or rising indicating very well whether there is much or little difference in the temperature of the currents it meets with.

After having, by a regular series of experiments, established the route of cold inlet fresh air, and discovered the cause of the draughts, the upcast aspiration of the vitiated air was taken in hand, and the three sun-burners re-arranged so that they drew off all the vitiated air from the hall, instead of, as before, taking the fresh air principally from the roof and to a great extent neutralising each other's action as ventilators. The same undesirable effect would be produced in the House of Commons when the windows are opened, if it were not for the fan, the action of which obviates this. The sun-burners are now provided with flashlights so that they can at any time be lighted when required, and their outlets fitted with ventilators as seen in Fig. 9, which are of the same pattern as the 4-inch and 6-inch ventilators described already, only 2 feet in diameter. The consumption of gas by each sun-burner is 250 cubic feet per hour, and they are each capable of extracting from 20,000 cubic feet of air with flashlights only alight, or from 70.000 to 80,000 feet, being an aggregate quantity of about 240,000 cubic feet, when they are lighting the hall. The extracting power is regulated by the admission of fresh air, which is now controlled from the hall.

The admission of fresh air is effected by means of eight ventilating tubes, each 2 feet wide by 8 inches high, regularly distributed on each side of the hall, and in communication with the exterior air of the roof. The mouths of these tubes, opening into the hall, are covered with zinc filled with holes which are funnelated as seen in Fig. 10, according to Normanton and Major's patent. The air is distributed all over the upper part of the hall without draught and at a very slow rate of velocity. The volume of air which the tubes are unitedly capable of delivering is about 80,000 to 100,000 cubic feet per hour, and this is generally enough for cold weather. If more is required for warmer weather, the two large ventilators, which are supplied with fresh air from the street, can be brought partially or fully into use. Each of these is 22 feet long by 2 feet 6 inches, and they are covered with zinc plates, filled with similar holes to those described, which break up the air into so many small and slowly moving streams that the entrance of a very large quantity of air cannot be perceived. Since these alterations have been carried out, the two balloons will rise steadily to the ceiling, up to the perforation of the sun-burners, where they generally stop. They do not now come down to the ground, and their circulation along the hall is very gentle. They feel the fresh colder air coming in at the large tube ventilators, which are about 15 feet from the ground, when they are open, and descend till they get near the middle of the hall, where the upward moving warm current takes them up to the sun-burners. Although this is not quite so perfect a system of ventilation as that of the Houses of Parliament, because it is not possible to bring the fresh air in from the ground level, and because in the position where the Mansion House is built it would not be wise to do so, yet the system of changing the air is satisfactory to the guests. It cannot be denied that a little of the vitiated air must get mixed with some of the fresh air, but it does not get a chance of descending anywhere near the guests, because as it mixes with some of the cold air it warms it and at the same time contaminates it, and rises with it towards the ceiling where it is carried off by the sun-burners.

The lighting and ventilation of a billiard room is shown at Fig. 11. The warming is done with hot-water pipes and radiators. If the room is used for matches, and a great number of people are likely to be gathered together, it must be warmed by steam.

Church lighting and ventilation are shown in Figs. 12 and 13; Fig. 12 being St. Michael's, Cornhill, and Fig. 13 St. Sepulchre's Church; the work having being carried out by the author, in the latter case about twenty years ago. St. Michael's is supplied with fresh air through the upper basket of the sun-burner.

The author has successfully carried out in the board room of the Gas Light and Coke Company a combined system of lighting and ventilation, in which the heat of the burning gas used for lighting has been utilised, not only to produce an upcast to carry off the vitiated air from the room and the products of combustion, but at the same time to induce and distribute all over the room a sufficient inlet supply of fresh air, without perceptible draught, through the same pendant, as shown in Fig. 14. The dimensions of the board room are 58 feet long, 24 feet wide, and 16 feet high, the capacity being 22,272 cubic feet of air. Fig. 15 is a section of the pendant. There are three of these fixed at equal distances apart in the board room, and one is fixed by itself in an adjoining committee room. The latter room is 28 feet long by 24 feet wide, and 16 feet high. All four are precisely similar in construction; 20 cubic feet of gas per hour is consumed by each of these pendants, and the volume of light given for this consumption equals that which would be given by more than 200 spermaceti candles of six to the pound, i.e. Parliamentary standard candles, all burning at once at the rate of 120 grains per hour each candle. The total volume of light in the board room is therefore equal to fully 600 of such candles. This high duty per foot of gas consumed is obtained by Sugg's patent Cromartie lamp, of which Fig. 16 is a section.

The gas supplied to produce the flame burns in a horizontal position, and the flame itself is shaped on plan somewhat like the flower of the camelia. The lamp is fed with a large quantity of atmospheric air, from which it takes the oxygen to produce in combination with the hydrogen and carbon of the gas a brilliant white light. The entire air supply to the lamp is about 10 cubic feet to 1 cubic foot of gas consumed. There are two distinct supplies of air to the flame, one of which descending through the central tube A becomes very much heated before it reaches the upper surface of the flame which it feeds, and the other descending through the apertures B is comparatively cold, and this feeds the lower surface of the flame (see Fig. 15).

Prof. V. B. Lewes tells us in his very useful book on Air and Water, that 100 feet of atmospheric air is composed of 20·61 feet of oxygen, 77·95 feet of nitrogen, 1·40 feet of aqueous vapour, and four-tenths of a foot of carbonic acid. There are traces of nitric acid, ammonia, carburetted hydrogen, sulphuretted hydrogen, and sulphuric acid in the air of towns. The oxygen and nitrogen gases are only mechanically mixed with each other, just as two quantities of different sized shot may be mixed together. It is very possible that the inert gas, called lazy gas, only lately actually discovered in atmospheric air by Lord Rayleigh, assists in keeping them together. Be this as it may, it is nevertheless a fact that the oxygen when it finds itself in proximity to the burning hydrogen instantly parts company with the nitrogen, for which it has no affinity, and joins the hydrogen, for which it has a most powerful affinity, and the two form acetylene and eventually carbonic acid, producing a brilliant light in the final stage of the process. It will be observed that if a lamp is supplied with 10 cubic feet of atmospheric air to 1 cubic foot of gas, there would be in this quantity about twice as much oxygen as would be necessary for the purpose of combustion. But the draught through the lamp is so rapid that more than half the oxygen supplied to it is carried off with the nitrogen, which escapes up the chimney with the products of combustion, carbonic acid and steam.

These heated products are utilised in the pendant light shown in Fig. 15, to produce an up-draught, much in the same way as the coke fire produces an up-draught in the clock-tower shaft of the House of Commons. This rapidly moving current is directed into the middle of the funnel A, and acting as an ejector, sucks in with it the vitiated air from the surface of the ceiling through the perforations in the lower part of the ceiling rose provided for that purpose. The heated products then pass up into the Sugg's ventilator, from whence they are extracted by the effect of the passage of the wind across the mouths of the tubes in the crown at B. The heavier cool fresh air descends by its own gravity through the outside casing of the ventilator into the chamber C, and is drawn into the room by the suction action of the heated column of vitiated air passing up the exit flue. The trumpet-shaped tubes serve to distribute it all over the room at a reduced rate of speed that is not felt. As the board room of the Gas Light and Coke Company is heated by two large coal fires, one at each end of the room, it has been necessary to fit two so-called Tobin tubes to supply extra air in winter, to prevent the fires from drawing too much on the fresh-air inlets of the lamps, and so making the inflow of air too rapid. The annular inlet air tube of the pendant is provided with a hit and miss arrangement (D D), so that the quantity of cold air admitted in winter may be checked. In summer, when the fresh air is not so heavy as it is generally in winter, the full inlet may be used.

There is another useful system of ventilation which the author has frequently made use of for the temporary ventilation of ball rooms, billiard rooms, dining and drawing rooms, &c. This system is totally different from the kindred systems described, depending as it does for its success upon the well-known law of diffusion, which may be described thus:—If two different chambers are put into communication with each other by means of an opening made in the dividing wall which separates the chambers, and this opening be entirely filled in with any porous substance, the contained air in the two chambers will mutually diffuse until it is of equal specific gravity in both chambers. Thus, if the air of one chamber is heated to 80°, and the air of the other is only 40°, the hotter air will diffuse into the colder air, and the colder air into the hotter, until they are both alike in temperature. Only that, as in the course of this operation the heated and more rarefied air passes through the medium more easily, and consequently more rapidly, than the cold or thicker air can pass through into the more heated chamber, a pressure is temporarily set up in the colder chamber, and this pressure may even reach something like several inches of mercury if the pores of the medium are as fine as those of earthenware or plaster of Paris. This process of diffusion is similar to the well-known Graham's dialysis process. The pressure can, of course, only be produced if both chambers are air-tight, except at the opening in which the porous substance is fixed.

In the application of this system to the purposes of ventilation, it is only necessary to fit a frame in the top half of a window, inside the room, and stretch over this frame a piece of muslin or silk or coarse canvas, or even fine perforated zinc or gauze, and then, opening the sash of the window to any required degree, allow the external air to diffuse into the internal air of the room, and a very good ventilation without draught can be obtained. In summer a large part of the entire area of the window opening may be safely used, and in winter, if it is very cold outside or a wind is blowing directly on to the screen, it may be necessary to hang a loose piece of muslin outside the screen towards the wind, which will prevent, even under those circumstances, any feeling of draught or discomfort.

When the British Association met at Southampton some years ago, the major part of the ventilation was done effectively by means of large open windows, in the top of a rather low hall, filled in with coarse canvas. The author, being suddenly called upon to ventilate this very unsuitable hall, devised this method and carried it out with success. In hot summer weather, especially in India and other places, a fine spray jet, Fig. 17, devised by Sir Goldsworthy Gurney, and used at the Houses of Parliament, will be found most useful, placed outside windows.

The limits of a paper do not permit the author to enter into descriptions of the many different modes of ventilating, warming and lighting halls and chambers which are in practice, but those systems described will serve as illustrations of practical ventilation without mechanical power, and very materially assist in enabling architects and engineers to decide on suitable methods to be applied to almost all classes of buildings.

In conclusion, the author would suggest that where it is possible to build in the walls of buildings a number of earthenware pipes glazed in the inside, and arranged so as to take off the vitiated air of chambers at the ceiling level, and to supply fresh air taken from the roof down other similar pipes, the inlets provided with funnelated openings distributed round the room such as have been described, most of the difficulties of ventilation will disappear. Of course in all buildings surrounded with pure air it might not be necessary to take the fresh air from the top of the building. If the openings for the admission of fresh air are sufficiently numerous and not too large, no draught will be experienced, although they may be pierced through the external wall of a room.

DISCUSSION.

The PRESIDENT moved a hearty vote of thanks to Mr. Sugg for his paper. He said that the subject of warming and ventilating buildings was one which many people fancied they knew a great deal about. The little knowledge he had of ventilation had been derived from being in houses in which the architect had provided for the ventilation by making a large hole in the ceiling for the purpose of allowing the escape of vitiated air. He had generally found that the holes, instead of letting bad air escape into the atmosphere, allowed the cold air to come down upon the heads of those in the room in such a way as to give them cold. In large halls where air-shafts were provided in the corners, he had observed that the cold air which entered made straight for the fireplace, and formed a very disagreeable draught to those who had to sit in the line of it. The paper showed that ventilation must be treated scientifically, especially in connection with large buildings where great numbers of people assembled. The paper was a most interesting one, and he had no doubt that it would lead to a good discussion.

The vote of thanks was unanimously carried.

Mr. ARTHUR RIGG said that of two systems of ventilation, the vacuum and the plenum, Mr. Sugg had described the one which he seemed to consider the best, namely, the vacuum system. But he (Mr. Rigg) believed, not in the vacuum system, but in the plenum system. He did not suppose there existed a single public or private room where decent ventilation could be obtained without a terrible draught, except perhaps the Egyptian Hall of the Mansion House, which Mr. Sugg had described as his most recent achievement. Every word which the author had said about restaurants and places of that kind was perfectly true, and there was no doubt that a great amount of scientific care was required in order to ventilate such rooms. The author's account of the House of Commons ventilation was exceedingly interesting; it was a subject which he believed had never been discussed at a public meeting, and was, no doubt, the result of what the author had called the wisdom of the "highest intellects," and, like most other things which came from the "highest intellects," it failed to work. The newspapers of the previous Tuesday had reported that Mr. Akers Douglas, the First Commissioner of Works, had stated that he would give his personal attention to the ventilation of the House; that was after the subject had been brought under notice more than once during the last session by Mr. Weir, the member for Ross-shire, and the statement did not look like a successful result of the aforesaid "highest intellects." He (Mr. Rigg) had gone all over the ventilating arrangements of the House of Commons, and it was a perfect marvel to him that Mr. Prim, the engineer, had been able to work the device as well as he had, for the system seemed to violate every law of science and common sense. The arrangements for heating were as good as they could possibly be, and the purification of the incoming air by cotton wool was excellent, but when the purification had taken place, the air went up into the House through the floor matting. Of all places, the worst channel that could well be found! When influenza visited the country, ministers of the Government seemed peculiarly open to attack, for they breathed this vitiated air more than other members of the Commons, perhaps on account of their more regular attendance. Not only was the purified air utterly spoiled before it reached the members, but the whole system was devised under a misapprehension. Sending foul air out at the top of a chamber, and bringing fresh air in at the bottom, seemed very pretty in theory, and if experiments were tried with balloons, the idea seemed to work out well. But they had to deal, not with air, but carbonic acid, a gas which was half as heavy again. In a church, for instance, at the commencement of a service, the air might be passably good, though it was bad at that, but later on, when all the air had got to practically the same temperature, down came the carbonic acid, and the result was that everybody became sleepy, and complained. Designers of churches seemed to have acted upon an assumption that London was the lightest place in the world, and that they needed to make thick walls to keep out the sun. Consequently the windows had been diminished to start with, and worse still, later on some of them were taken out and replaced by stained glass memorial windows, never made to open; and thus even the original means of ventilation, barbarous enough, was absolutely taken away, and things became worse than ever. As an example of a church badly lighted and ventilated, he instanced St. Mary Abbott's, Kensington, where every law of nature and every rule of common sense had been set at defiance. When gas was used the church was unendurable, and now it was fitted with the electric light, but the congregation could not even see properly to read the words of the hymns.

As to the "highest intellects," he did not know who they were in the House of Commons, but he believed that really the highest intellect in France in connection with ventilation was the late General Morin. He arranged a good system of ventilation in Paris, which, when put into the hands of an architect to carry out, was carefully spoiled!

To give another instance. When the new University of Glasgow was about to be built, a committee, of which Lord Kelvin was president, considered the whole subject of its ventilation, and made a very elaborate, interesting, and valuable report. They stated that the fresh air ought not to be let in at the bottom, and the foul air ought not to be taken out at the top, thus inconsiderately reversing all the beautiful things to which Mr. Sugg had called attention. Of course, air would always go wherever it was driven, but the natural course of ventilation was downwards and not upwards. Even the position of the human nostrils served to illustrate that fact. He supposed the architects of Glasgow University possibly did not understand the system recommended in the report, for all sorts of conduits were arranged underneath the building, and those got mixed up with the sewers, so sewer gas got into the rooms of the building, an ancient, fish-like smell pervaded the place, and the whole scheme of ventilation was a failure. That result was not the fault of Lord Kelvin, nor of the scientific committee over which he presided, but was due to the idiotic way in which their recommendations were carried out. A consequence was that the Glasgow University is one of the worst ventilated, instead of being one of the most scientifically ventilated places in the kingdom. He believed that buildings generally were put up without the slightest notion that people really did need to breathe fresh air. Another style of blundering was illustrated by a building not very far from the hall in which the present meeting was being held. There an elaborate system of ventilation had been arranged, so that the air might enter cold at the bottom, and pass out heated at the top. When the scheme was carried out, it was found that, though the cold air came in all right at the bottom, the foul air failed to go out at the top, because it was met by the cold currents descending from the roof. The heating apparatus was increased, and to mend matters the windows were opened, but that change made things ten times worse. Another heating apparatus was therefore put in the roof, so that the air which came down upon the heads of the company should not be too cold.

Of the various schemes which Mr. Sugg had arranged, that shown in Figs. 14 and 15 appeared to be the best, if a vacuum system was to be adopted at all, because, although the foul air was taken from the top, which was wrong, fresh air was admitted from the top, which was right. A mixture of right and wrong was, of course, preferable to a system which was altogether wrong. According to Mr. Sugg, that system appeared to be fairly successful. He believed that if fresh air was judiciously let in at the top in the House of Commons the place would be a vast deal more comfortable. The balloon test described by the author was exceedingly interesting, and he believed that it might very well be applied in other directions, such as school buildings, as their ventilating arrangements were a disgrace to civilisation. Poor little children, boys and girls, sat for hours shivering from cold in their schools in consequence of the teachers, finding no other way of getting fresh air, opening windows, not where they themselves sat, but towards that end of the room where the children sat. Judges in the law courts also acted on the same selfish principle with regard to the opening of windows. Such a mode of procedure was not confined to our own country, for he recollected hearing a bishop preach in America for over an hour, interspersing his sermon from time to time with remarks on the condition of the atmosphere, and giving directions to open the windows because he could not stand the heat, and then to shut them again because he could not stand the cold. The whole discourse was mixed up with the question of opening and shutting of windows, which certainly did not improve the dignity of the occasion.

Mr. **Chas. Gandon** said that the description of the ventilation arrangements in the House of Commons had interested him very much, and he was inclined to agree with Mr. Sugg that it afforded one of the best illustrations we had of the subject. He, however, agreed with Mr. Rigg that it seemed to be a mistake to bring the fresh air into the building through the carpet. He would direct his remarks more particularly to private houses, as he did not think he had ever met with a well-ventilated house. In the place where the foul air was supposed to go out, the cold air generally came in, because there was no other place at which it could enter. To some extent cold air came in through the cracks of the doors and windows, but most of that which so entered went to supply the fire. The ventilation of small rooms seemed a far more difficult matter than that of large spaces. In the first place the supply of money at command was less limited in the case of large buildings than in the case of small ones; and large spaces could also be ventilated with less liability to draughts. In connection with the Debating Chamber of the House of Commons there appeared to be two other chambers concerned in the ventilation; one below for the admission of the air from the exterior, and one above for drawing away the foul air from the top. The draught was spread equally all over the area. It would be, he supposed, perfectly impossible to apply such a system to private dwellings, but still there was room for improvement in such places. One suggestion which he had met with, and had applied with apparent success in his own house, was to bring a separate supply of air from the outside to the fireplace. He believed that the supply of fresh air to the rooms could be effected to a great extent by Tobin ventilators, but the great difficulty was to get the vitiated air out, and he had never met with a good way of doing that. Perhaps Mr. Sugg could suggest how that could be done at a moderate expense. The question of cost was, of course, a thing which householders looked to.

Mr. **J. Jeffreys** said that the system of ventilation in use in the Houses of Parliament, described by the author, in which fresh warmed air was introduced at the floor level through interstices in a string carpet, was objectionable, and presumably dangerous to health, as the fresh air was liable to be contaminated by particles of dust set in motion by the rising column of warm air. It was possible that the recent spread of influenza in the House was attributable to that cause, members and attendants conveying on their shoes the seeds of infection from contact with the mud of the streets impregnated with sputum and other abominations. As dust naturally fell in still air, it would appear desirable to introduce the fresh air at a higher level, at least 6 feet above the floor, and in winter it should be warmed to a temperature of not less than 55 degrees, and not more than 65 degrees, Fahrenheit, in ordinary cases. If heated much above the temperature of the room, it would rise in the direction of the ceiling, and be lost for purposes of ventilation. If the fresh air was two or three degrees cooler than the air of the room, it would slowly fall by gravitation in the direction of the floor without sensible draught, and displace the warmer and vitiated air, which would escape at the ceiling, when suitably designed outlets were provided for the purpose, and efficient provision made for warming the glass, wall, and roof surfaces. If any portion of the building, such as a skylight, was insufficiently warmed, the vitiated air would be cooled by contact with such surface, and fall to a lower level to be breathed over again. In churches and lofty rooms it was often desirable to fix heating pipes at a considerable height from the floor, to counteract the cooling effect of the exposed surfaces, and prevent down-draught. Ventilating radiators, heated by steam or hot water, fixed round the walls of the chamber to be warmed, gave good results, but, as commonly made, they overheated the fresh air admitted between the tubes.

Much depended upon the shape of the fresh air inlet, which should be long and narrow, to better diffuse the cooler air through the warmer air of the room. When cold air was admitted through a square or circular Tobin tube of large sectional area, the air, after rising to a certain height, fell in a cascade in the direction of the floor at an angle varying with the relative difference in temperature, producing strong local currents or draughts. Even with the precaution described, the fresh air should always be warmed to some extent in cold weather, as sensitive persons were unable to bear a difference of 10 degrees Fahrenheit without discomfort. For extracting the vitiated air where mechanical ventilation was inadmissible, the system known as assisted ventilation, namely, flues in the internal walls fitted with wind cowls on the top, and gas fires at the base for use in still air, was effective when the sizes of the flues were properly considered. Some tests recently made in a large public building, ventilated as described, had given a flue velocity of 10 feet per second, with a moderate consumption of gas. The system of extraction in use in the Houses of Parliament, of collecting trunks, connected with a central aspirating shaft, was unsuitable for buildings of extended area, with numerous subdivisions and several floors, on account of the difficulty experienced in regulating the exhaust from each room, due to variations in outside wind pressure and leakage in the trunks, the latter increasing with the length. Apart from these considerations it was generally impossible to induce architects to make the necessary provisions in the building on the score of expense and space occupied.

Nothing that had been said was directed against the use of fan ventilation, which was absolutely necessary in many cases, but what had been said was rather in favour of an alternative cheap and effective system, suitable for the majority of public and private buildings of moderate size.

Mr. W. SCHÖNHEYDER said that he had been interested in the paper, and especially that portion of it which described the ventilation of the Houses of Parliament; but he was far from agreeing that that system was so perfect that it was worth while to imitate it. That the House of Commons was bearable was, he believed, entirely due to the admirable way in which Mr. Prim managed the arrangements. People had a false idea that all foul air must necessarily rise, and that the foul air must be kept separate from the fresh air which entered an apartment. When the foul air of the human body was sent downwards by the nostril, the fresh air which was drawn in must meet and mix with it to some extent. Gaseous bodies were diffused into one another with such rapidity that, if a match or a cigar was lighted in one corner of the room, the smell very quickly reached another corner. The fresh air and the foul air would mix in all directions. The net quantity of air which a man required for breathing was, he believed, the small quantity of about 16 cubic feet per hour, but about a hundred times that volume was required in order that the impurities might be diluted to such an extent that they were not harmful. It was of no use to talk about keeping the foul and the fresh air separate, for it could not be done. What had to be done was to try to arrange matters in such a way that no draught was created. That could only be done by keeping the air in the upper part of the room warmer than that in the lower part. When the air cooled it descended and formed nearly horizontal layers, the warmer on top of the colder, like oil floating on the top of water. Endeavouring to get the warm air at the bottom and the cold at the top was like trying to get water to float on the top of oil. He had ventilated and warmed his own house on the plan of admitting the warm air at the top, and withdrawing the cooled air from the floor level. He never opened a window during the whole winter, except for cleaning purposes, and the air was always perfectly fresh, as ventilation was going on continually, night and day. He never allowed any air to come into the house through the w.c., as it would only carry the effluvia into the house. On the contrary, he took the air from the house through the w.c., and the foul air away from the rooms at the bottom. The warm air which came from the house into the w.c. was necessarily warmer than the rest of the air there, and rose to the ceiling. It was cooled by contact with the walls and the window, and gradually descended, carrying the effluvia with it down to the floor. The w.c. was consequently always warm and comfortable even at night, and there was no draught nor foul air. He would ask Mr. Sugg why he thought that only steam could accomplish the heating of the House of Commons. If only a moderate temperature was wanted, hot water was better. Mr. Sugg has said that the air entering the House of Commons at the lower part had a certain velocity, and the velocity increased as the air got nearer to the ceiling. But it seemed to him (Mr. Schönheyder) quite impossible that the velocity should increase in that manner. He could not understand the diagram referring to the sun-burner ventilator. He should expect the air to go in the reverse direction to that shown by the arrows, so that there would be no change of air at all in the apartment.

Mr. St. George Moore said he would describe a method of ventilation which he had adopted in a building under rather peculiar circumstances. The ventilation was that of the pavilion of a pier. There was any quantity of good air outside, but the difficulty was to get it into the building in the form that was wanted. The building was octagonal, 65 feet across the flats, and had a total height of 54 feet. The section of the wall was continuous for six-eighths of its circumference; and the rest was occupied by the annex, containing the various subsidiary rooms to the concert hall. The first inlet, 5 feet above the ground level, had been so arranged as to give a long, narrow opening, in fact, the opening, which was about $\frac{3}{4}$ inch wide, was continuous round six-eighths of the room, so that the air was diffused. Immediately under the gallery there was an outlet which would be 13 feet above the floor. The ventilation of the gallery was carried out in a similar manner. The main aspirator was in the lantern, which had outlets equal to about $4\frac{1}{2}$ square inches per person, the sunlight being placed about 6 feet below it. The pavilion on the pier was used only in the summer, when the outside air was very hot; in other words, when there was the greatest need of ventilation. The practical experience gained was that, when there was the slightest movement of the air outside, the system would work all right, confirming Mr. Sugg's remarks as to the increased effect of the aspirators when the air was in motion; and the room could be kept at a very comfortable temperature. But on hot nights, the absence of movement in the outside air reduced the efficiency of the aspirators, and the temperature in the hall rose very rapidly, and he honestly confessed that on those nights the system failed.

Mr. PERCY GRIFFITH said that, being himself concerned more with heating than with ventilation, he should have preferred the author to have dwelt more on that part of the subject than he had done. The author had shown that ventilation was more easily combined with lighting than with heating. He gathered from the paper that it was more difficult to bring about a connection between heating and ventilation than between lighting and ventilation; but he should have liked some advice from Mr. Sugg with regard to the former. With regard to the source of heat for warming buildings, he would ask Mr. Sugg whether the use of exhaust steam, rather than live steam, for that purpose was considered in carrying out the warming arrangements of the House of Commons. The use of exhaust steam constituted his (Mr. Griffith's) only experience in the branch of work under consideration; and the case in which he had adopted it had been very successful. They would also like to know, as engineers, as well as private individuals, what was really the best way of ventilating a room, although it seemed to him that ventilation, pure and simple, was more a matter for the architect than the engineer. His own experience had been that, whether they attempted to take air up, or to take it down, it went in most cases—at any rate in private houses—in a contrary direction to that in which it was intended to go.

One mistake which was apparently made pretty often, was that in most systems of ventilation it was taken for granted that the building was air-tight. In most of the cases which had been referred to, it would be absolutely necessary for the buildings to be practically air-tight in order that the air, whether pure or impure, might follow the directions which were indicated by the arrows on the diagrams. Of course the work of ventilation would be much more simple if only the air currents would follow the directions in which they were intended to go, and in which it seemed so obvious that they would go, judging from the systems adopted and shown so graphically on the diagrams. But, as few buildings were air-tight, it was impossible to foresee definitely what would be the result of any particular scheme of ventilation. One fact which he thought would strike every one present was that the paper was written by a gentleman who was associated with gas apparatus; and that suggested a point which he (Mr. Griffith) considered worth noticing, viz. that in adopting the modern rival of gas, viz. electricity, for internal lighting, a very valuable factor in the ventilation of any room, large or small, was lost. Of course gas was itself a serious impurity when consumed in ordinary unventilated rooms, but being such a nauseous vitiator of the air, it was absolutely necessary to get rid of it somehow, and in doing so some system of ventilation, however elementary, was perforce adopted. What he meant was that the evil arising from the burning of gas was apparent, and thus called attention to itself, demanding an immediate remedy. In cases where gas lighting was done away with and electric lighting substituted, there remained an evil which, because less apparent, was less likely to receive proper attention. The foul air resulting from the consumption of gas, although very similar in composition to that emanating from the human body, was much more pungent and objectionable to the senses, and called for the opening of windows or other means for getting rid of it, if it was present in any quantity at all. But the emanations from the body, being less palpable to the senses, were more likely to be allowed to accumulate to a sufficient extent to do harm. That was, of course, a negative argument, but it was worthy of consideration. The question of ventilation was very much more serious and important in the case of electrically lighted rooms than in the case of rooms illuminated by gas. The condition of things was apparently more healthy, but the danger was really greater, because the evil was not so apparent.

Mr. A. E. Hubert said that the evil of bringing the fresh air for the House of Commons up through the carpet at the floor level was well known. In fact, Mr. Sugg had himself alluded to the defect in one part of his paper. The remarks of one of the speakers showed that the ventilation of the House of Commons was not by any means the success which the paper would naturally lead them to conclude. He agreed with one or two of the speakers, that it was very much better to admit the fresh air at a high level, and to diffuse it in as thin a film as possible to prevent any draught being noticeable. As to the means of extraction from the House of Commons, part of the air was taken from the top and brought down by an elaborate system, and taken under the building for a long distance to the clock tower. It would be much more simple to draw the bad air away from a number of small openings at the floor level, and to bring the fresh air in at a level of about 6 or 7 feet. He believed that that plan would have led to far better results than were now obtained. He found that, in all large buildings, it was much better to admit the air at a height of about 6 feet than at a higher level or near the floor. As one of the speakers had remarked, the diffusion which took place rendered it impossible to bring the pure air in at one place, and take it off at another. Diffusion took place so rapidly that they could not hope to get air in at one point, and let it pass through a room or building, and take the foul or vitiated air off at another point wherever that might be. They could only hope to get the air so constantly diffused that it never got into such a dangerous state as to make it unhealthy to breathe. The better plan was to bring in the fresh air heated at as many points as possible, and in a thin film, as it were, when it was convenient to do so, in order to prevent draughts being felt. They had, perhaps, seen advertised "Ventilation without Draught." That was quite an impossibility, for there must be draught of some kind; but the draught should be minimised as much as possible, and they should get as much diffusion as they possibly could in the manner referred to by him. It was not possible to deal with a small building in the same way as a large one. In a private house it was quite an impossibility to adopt economically mechanical means of ventilation in some cases, even to the extent of having separate flues. The fireplace must be relied upon for the purpose of carrying off the vitiated air, in the winter time, at any rate. The fireplace was a very good means for extracting the bad air in small dwellings, provided that the inlets were in the proper places; and it was also an inexpensive method. The fresh air admitted through specially placed inlet openings should be at a somewhat higher temperature than that at breathing level in the room.

Mr. M. SHILLITO said that he was surprised to find so much made of the ventilation of the Houses of Parliament. When he went through the building he could only think of the splendid opportunity which had been missed. He thought that a description of the ventilation of the German Houses of Parliament at Berlin as carried out in recent years by Mr. Grove, would be a much more profitable subject than the account of the English Houses of Parliament. In the German building the ventilation was carried out mainly on the plenum system, by means of about a dozen Blackman fans up to 7 feet in diameter, and the heating was, as a rule, effected by means of steam, though the best apartments were heated by hot water. An example of ventilation often occurred to him when he heard small details being discussed. It was that of a large woollen factory in the North of England where a system of ventilation better than that to be found in any public building had been unintentionally set up. It was effected by means of a 48-inch Blackman fan giving 20,000 cubic feet of air per minute which had been supplied for the purpose of drying wool. The wool was spread on wire tables of an area of 500 square feet, standing in a large room. The wool lay in a mass of about 6 inches thick, and the air exhausted by the fan had to percolate downwards through it. The air was admitted into the room through numerous gratings in the ceiling from the room above, and the latter room was in turn supplied with air from a room above it, and so on through several large floors. That process went on without any perceptible draught. No current of air could be detected by means of a lighted match, and even long suspended fibres of wool were scarcely swerved from the perpendicular.

He had not found it very difficult to ventilate a private house. He used practically the same apparatus as that which was used by Professor Tyndall and exhibited in the Health Exhibition of 1884. The apparatus was placed in the basement of the house, the only inlet of the fresh air being through it, and the air was thus raised to a temperature of about 100 degrees by passing through vertical tubes or their equivalent, into an air chamber in the ceiling of the basement, and then it was led through ducts formed in the wall. After the house had been built with this ventilating arrangement he asked the builder how much extra he had spent on brickwork in carrying out the ventilation, and he replied, "Certainly not more than *3l.* or *4l.*" The warmed air rose to the ceiling of the rooms at an angle of about 45 degrees. No rapid motion of the air took place. It descended as it cooled, mainly near the windows, and when the air came to the level of the fireplace, it passed out by the chimney. The coke fire used in the apparatus, costing about as much as an ordinary kitchen fire, served to ventilate and warm eight rooms of the house treated. The system had been in use about three or four years, and he had never heard anybody complain of a draught.

Mr. THOMAS KIRKLAND said that the valuable paper which Mr. Sugg had read was a record of practical work, and, as such, was of more use than a statement of mere theory. What they had heard to-night showed how very difficult it was to be certain of what they were doing with regard to ventilation. He agreed in the condemnation of the use of the carpet in the Houses of Parliament for the admission of air. Not only were microbes, or whatever the agents of disease were which floated in the air, absorbed by a carpet, but they were liable to be found in any duct which might be employed for the admission of air; therefore all air ducts should be so placed that they were accessible for cleansing, as after a time the ducts became charged with dust, and bacteriologists would agree that there was nothing more likely to be deleterious and injurious to the public health.

Mr. J. W. WILSON, jun., said that his experience as a churchwarden had led him to be rather sceptical as to what was said by members of a congregation with reference to the draughts in a church, because persons who had sat within a few feet of one another would state very different experiences. Some of them would complain of a terrible draught, while others would declare themselves to have been almost suffocated for want of ventilation. Mr. Sugg had taken 30 feet as the quantity of air supplied to each member in the House of Commons per minute. M. Morin, whose authority on such subjects was perhaps paramount, estimated that the quantity required was from 15 to 20 feet. There was an important difference between the two amounts; the author would doubtless be able to throw some light upon them. It was important that, when a system of ventilation carefully adapted to particular conditions had been set up and the building had been handed over by the builder, there should be some guarantee that the ventilating apparatus and all matters connected therewith should be placed in charge of a person who understood how to manipulate them. Unless a system of ventilation was worked properly, it might do harm rather than good, and thus bring undeserved censure and discredit upon those who had originally arranged it.

Mr. K. J. G. Read said the subject of ventilation seemed to divide itself into two branches, namely, the ventilation of public buildings and the ventilation of private houses. As to the system used at the House of Commons, he thought that enough had been said to condemn it. It occurred to him that the hall in which the members were then assembled appeared to be very well ventilated and very comfortable, and he felt much fresher than he had felt on many occasions at the meetings of the Institute of Civil Engineers in the old meeting hall. He should like to know where the air entered the hall in which they were now met, and where it went out. He quite agreed with what had been said about churches. They were generally very badly ventilated, and he gathered comfort from what a former speaker had said, that there was some excuse for members of the congregation going to sleep besides the dryness of the sermon. The ventilation of private houses was the part of the subject which concerned the greatest number of people, but he had gathered that it was a very difficult thing to bring about. He tried to warm his house by means of a stove in the hall, the flue pipes being carried through the wall into the outer air, as there was no chimney, but he could not get a draught. He then bought from Mr. Sugg a ventilator, and he put it on the pipe, but still he was unable to get a draught. He then pulled out the ventilator and pipe and took the pipe across the ceiling of a small room which he used for his study, and carried it into the flue of the chimney, and then the stove acted properly; and the pipe which went along the ceiling warmed the room almost sufficiently to enable him to sit in it without a fire. A neighbour of his had built a house with chimneys and fireplaces in the usual way, except that the smoke went up a pipe inside the chimney and cold air was admitted from outside to the bottom of the chimney, and passing up was warmed by the smoke pipe and then admitted through openings into the rooms. That seemed to warm it very well and prevented draughts.

Mr. Charles Erith said it was very remarkable that no reference had been made to the prevalence of mechanical systems of heating and ventilation in America. The installation in the House of Commons was only a crude example of mechanical methods, but when properly carried out mechanical heating and ventilation was a very economical system. In the House of Commons the extraction of the foul air was left to aspiration instead of being done by mechanical means. The latter would be much cheaper. The Hamburg City Hall afforded a good example of ventilation. All over America and in many parts of this country similar installations could be seen, and it was only a matter of time for them to be applied to all large buildings.

Mr. Sugg, in reply, said that the subject of the paper was a very large one, and he was not at all surprised that there had been a very great divergence of opinion amongst those who had taken part in the discussion. He had instanced the system of ventilation of the House of Commons because he happened to know a great deal about it, and he had described it in great detail, so that if anybody thought that the views which he entertained upon the subject were wrong, he would be able to say so. Mr. Rigg and others had objected to the fresh air supplied to the House of Commons coming through the carpet. The carpet, however, was simply a string carpet with a mesh of about an inch, so that it really did not act like an ordinary carpet in collecting dust; and inasmuch as it was brushed every morning, he did not think that much dust lodged in it. The dust which went through it would fall into the space below. He had understood Mr. Rigg to say that the natural course of ventilation was downwards, and that the carbonic acid ought to be brought downwards. Perhaps members were not aware that the direction of the entire ventilation in the House of Commons could be reversed in about ten minutes. It could be directed either from the bottom to the top, or from the top to the bottom. The experiment of reversing the ventilation had been tried on several occasions, but he believed that the general verdict was that it was better to take the air from the bottom to the top.

As to the Mansion House, he had explained in his paper that the inlet air was not taken from the ground level. He did not think it would be advisable to take it from that position, as there was a great deal of dust and other objectionable dry matter on the ground, which would spoil the quality of the air. That being the case, it was better to take it from the roof. As to the House of Commons, his own opinion was that it would be better if the fresh air was taken from a height of about 60 feet, instead of from the level of the terrace, as at present. However, there was the whole width of the river in front of the inlet, and he did not think the air could possibly be bad. If the supply was taken from the height of which he had spoken, the odour of a passing tar barge would probably not enter the House in the way which he had described in the paper.

With regard to the exhalation of carbonic acid in the breath, it must be remembered that the air which came out of the lungs was not simply carbonic acid; a great deal of it was nitrogen, and it was always mixed with steam and some unabsorbed oxygen, and the nitrogen and the carbonic acid were both heated by the steam, which, having a great specific heat, had not much chance of getting cooled until it rose some distance in the atmosphere. That showed that the only way of ventilating was to carry the air off at a greater height than the heads of the people. In the case of buildings other than the House of Commons, it would very likely be better to admit the air at a height of 6 feet from the ground, as was done by means of Tobin's tubes, or better by funnelated openings, and to carry the vitiated air away at the ceiling level. Mr. Jeffreys said that if the air was brought in above the heads of the people at a temperature of 2° or 3° below the temperature of the room, it would descend. That was quite clear. In any system of ventilation, if the inlet air was very cold, means must be taken to warm it, or else it was natural that the coldness of the air would be felt.

Mr. Schönheyder had mentioned that an ordinary gas burner would keep up the temperature of the upper part of the room, whereas the electric light would not do so. The products of combustion of gas being mostly steam and carbonic acid (every cubic foot of gas burnt producing two cubic inches of water), a very large quantity of water would soon be produced. That was carried up in the form of steam to the ceiling, and, on account of its specific heat, it kept warm very much longer than atmospheric air or carbonic acid gas would if they had no steam mixed with them. The same speaker said that he did not understand that the air coming in on the ceiling level would go into the room in the way shown on the diagram. The diagrams however showed that when the air came out at the ceiling it would spread itself all over the ceiling, and gradually settle down. It might be thought that directly it turned round it would rush up the sun-burner, but it did not do so. Being cooler, it always spread itself over the room in a lateral direction, and gradually sank down, and, of course, if any of it got warm by means of the vitiated air which it touched, it must go up. Mr. Griffith said that ventilation was the work of the architect. Ventilation was, however, taken up by engineers as a speciality, and the architect, as a rule, found that the best way of proceeding was to get the ideas from somebody who was specially engaged in the particular work of ventilation, and incorporate them in his plans.

As to steam-warming, the reason he had mentioned it was that he thought that, generally speaking, where the temperature had to be altered suddenly in five or ten minutes, the change could not be accomplished rapidly by means of hot water. If water was used it would take some hours to bring about the change, whereas by means of steam the alteration could be produced at once. The system of using waste steam for warming was, no doubt, an excellent thing, when it was properly regulated.

Mr. Shillito had referred to the ventilation of the new German Houses of Parliament at Berlin, by means of Blackman fans. Of course, whether they had a Blackman fan or a shaft, it was the same thing. They could put air in motion by means of either appliance. He supposed that in the case referred to the Blackman fan was found more convenient.

Mr. Shillito said that the ventilation referred to was mainly on the plenum system.

Mr. Sugg said that he did not much care about the system, but he doubted whether they got what was called a plenum, meaning a room in which the air was under pressure. He had pointed out that, in the House of Commons, it was impossible to say that they had got a pressure. It was difficult to produce anything like pressure. They could get a roomful of air, but, as to getting any pressure of air, he did not think it could be accomplished in rooms with doors and windows or fireplaces in them.

Mr. Shillito said that, as far as he knew, there was no object in getting a pressure.

Mr. Sugg said they had got a plenum in the present room. Some people understood by plenum merely a fulness, and others understood it to mean that there was a kind of pressure. Mr. Read had hoisted him (Mr. Sugg) with his own petard, and had said that one of his ventilators had failed to act as intended. He did not know the circumstances of the case, so he could not explain the reason. Mr. Wilson had illustrated the troubles of a churchwarden. He (Mr. Sugg) happened to be a churchwarden, and he found exactly the same thing as Mr. Wilson had described. One member of a congregation would say that the draught was "something awful," and another would say that he did not feel anything of it. One would say that the church was stuffy and hot, and another would say that it was awfully cold.

PLATE I.

FIG. 1.

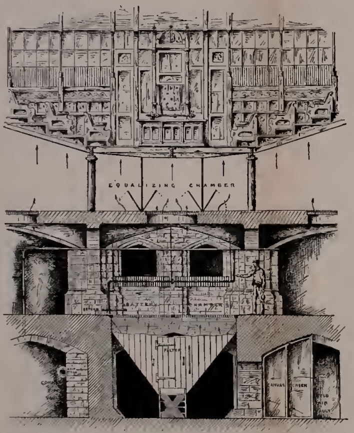


FIG. 2.

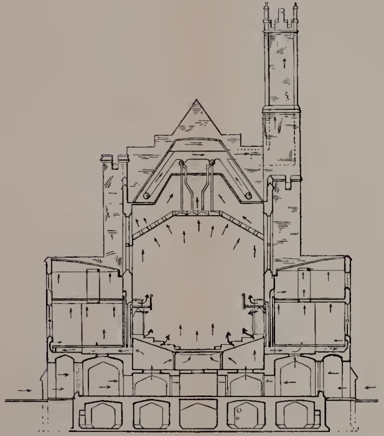


FIG. 3.

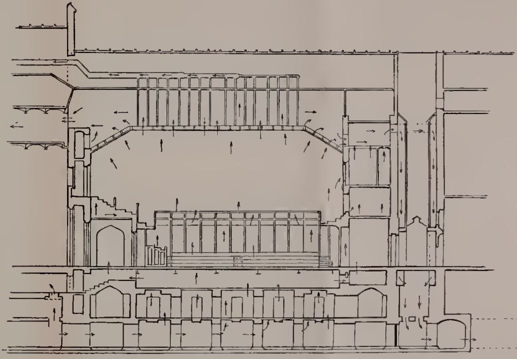


PLATE II.

FIG. 4.

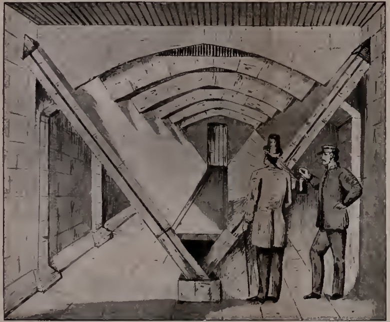


FIG. 5.

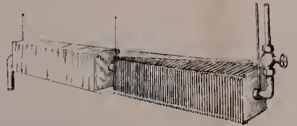


FIG. 6.

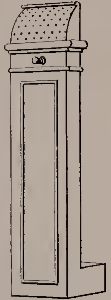


FIG. 7.

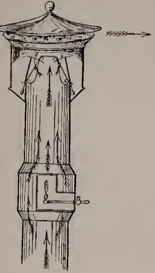


FIG. 8.

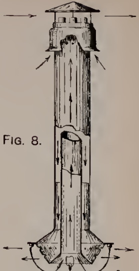


FIG. 9.

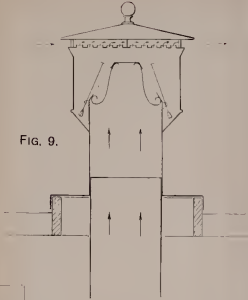


FIG. 10.

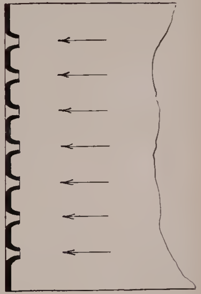
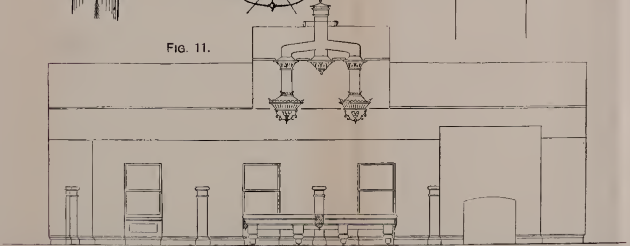


FIG. 11.



Obituary.

WILLIAM HENRY HARDY, who died on the 13th of January, 1895, was born at Brighton on the 12th of November, 1823. In 1847 Mr. Hardy was appointed to a clerkship in University College, London, which he held for seventeen years. Having a predilection for science, he devoted his leisure time to study and attended the scientific lectures delivered at the college. He also studied chemistry at King's College. On resigning his appointment at University College he commenced practice as a chartered accountant, and subsequently became secretary to the Brighton and Hove General Gas Company; the Colney Hatch Gas Company; the Goring and Streatley Gas and Water Company; the Mid-Sussex Water Company, and the Mill Hill Gas Company. Mr. Hardy was elected an Associate of the Society in 1880. He was also a fellow of the Statistical Society, a member of the Microscopical Society, and a member of the Kent Archæological Society. Possessing considerable artistic talent, he was also elected a member of the Royal Society of British Artists.

HENRY POPPLETON, who died on the 6th of March, 1895, was born at Wakefield on the 18th of March, 1821. He was educated firstly at the Moravian School at Fulnek, near Bradford, and afterwards at the West Riding Proprietary School, taking there a high certificate in mathematics. On leaving school he was articled to a civil engineer, who died before the expiration of Mr. Poppleton's term of pupilage. He subsequently held a mastership for teaching land surveying and agricultural chemistry in an agricultural school. In 1841 he settled down in Farnham, Surrey, where he established a school, which he successfully conducted until within a few years of his death. Mr. Poppleton was elected a member of the Society in 1874.

RICHARD DUDGEON, mechanical engineer, who died on the 12th of April, 1895, at New York, U.S.A., in his 73rd year, was elected a member of the Society in 1868. He commenced business as a manufacturing engineer in 1848, and was the inventor and patentee of the hydraulic jacks, roller-tube expanders and various other well-known mechanical devices bearing his name.

JOHN ANTHONY COWEN, who died on April 14, 1895, was the son of the late Sir Joseph Cowen, and was born at Blaydon Burn in June 1831. He was educated first at Ryton, and afterwards at the College of Civil Engineers, Putney. On completing his education he joined his father's firm at Blaydon in the business of fire-brick and clay retort manufacturers. He was one of the oldest members of the Society, having been elected in 1858. He was chairman of several local manufacturing companies, a justice of the peace, and county alderman for Durham, and a River Tyne Commissioner. Mr. Cowen was one of the oldest volunteers in the north of England, having joined the 5th Durham Riflemen at an early age, and passed through every grade to the position of Colonel. He was the recipient of the long-service medal.

JAMES SCORGIE, who died on July 15, 1895, was born in Aberdeen on March 16, 1835. He received an elementary education in one of the parish schools of that city, and in 1850 was apprenticed to a firm of brass-founders there. During his term of seven years with that firm he improved his education by private study, and by joining various literary clubs. He also attended evening classes in connection with the School of Science and Art which had then just been started in Aberdeen. In 1855 he gained the first prize for chemistry at the Government Examination, Aberdeen School of Science, Session 1854–55, which, besides a medal, consisted of a free studentship at Marischal College. This latter was given by the Board of Trade. In April 1856 he received a certificate for distinguished proficiency in chemistry, and in April 1857 a certificate after a competitive examination on the Fordyce Lectures on agricultural chemistry, besides a testimonial from the mathematical class. It was his intention to have pursued his studies at college as a medical student, but as circumstances did not permit of this, he left for London on February 20, 1858. Later on in that year he went to Bombay, and soon obtained there an appointment in the locomotive department of the Great Indian Peninsular Railway, where he remained for sixteen months. From thence he went to the locomotive department of the Bombay, Baroda and Central India Railway at Amrolie, near Surat, where he remained until November 1861, when he was appointed Engineer's Assistant on the Railway Bridge at Bassein. At the time of its erection this bridge was the largest in the world, its total length being 4312 feet.

In 1862 Mr. Scorgie entered upon his educational career, having been then appointed teacher in the Free General Assembly's Institution at Bombay. He remained there until

1865, when he became Acting Principal of the Sir Jamsetjee Jeegeebhoy Institution at Bombay. Connected with this institution was the large central school with about 600 pupils, and 22 branch schools, with about 4000 pupils in all. In 1866 he was appointed Head Master of the Akola High School at Berar, and remained there for six years. For his work there he received the thanks of the Government for his "zealous co-operation in the good work of spreading education throughout the province of Berar; carried on as it had been without offending the prejudices of the people." At the request of the Maharajah of Jeypoor, he was transferred to that State in 1872. There he re-organised the School of Industrial Arts, carried out some successful improvements in the art of dyeing and printing calicoes, and introduced the glazing of pottery-ware. These services were noticed by the Maharajah with much satisfaction.

In 1875 he was appointed Professor of Mechanics and Applied Science in the Civil Engineering College at Poona, and there he remained for fifteen years. He was elected a Fellow of the Bombay University in 1868, and was one of its examiners, appointed yearly until he left India. In 1890 he retired from the Indian Educational Service and returned to Aberdeen. During his last years in Poona he compiled for the use of his students 'A Short Treatise on Building Materials.' He was elected a member of the Society in 1865.

SOCIETY OF ENGINEERS.

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